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BRIEFS

INDO-HUNGARIAN MEDIA COOPERATION--India and Hungary have agreed in principle to have wide-ranging mutual collaboration in the field of radio, TV and other mass media to strengthen their bilateral relations. This was disclosed by the visiting Hungarian minister for information, Doctor Peter Varkonyi, after 2 days of talks with the minister for information and broadcasting, Advani, and other Indian leaders in New Delhi. [Text] [Delhi ISI in English 1449 GMT 3 Nov 77 BK]

CSO: 5500

DIGITAL SATELLITE GROUND STATION OPERATIONAL

Peking NCNA in English 0813 GMT 8 Nov 77 OW

[Text] Peking, 8 November 1977 (HSINHUA)--The first digital satellite communication ground station designed and built by China has been put into operation with satisfactory results. The double-channel colour television programmes relayed by the station from communication satellites are clear and the sound effect is excellent.

The new station will be used to transmit the format of the PEOPLE'S DAILY, radio and television programmes and other radio messages from Peking to far-off areas. It is of tremendous importance for enhancing China's endeavours in satellite communication and oceanic communication, accelerating the modernization of telecommunications, developing the national economy and space projects and strengthening national defence.

China built an analogous satellite communication earth terminal in 1975. Coming into use in a number of countries toward the end of the sixties and the beginning of the seventies, digital satellite communication is highly resistant to radio interference and ensures greater secrecy.

Both Chairman Mao and Premier Chou attached great importance to the development of satellite communication and related projects. Encouraged by their close attention, scientists, technicians, cadres and workers cooperated closely in the course of designing and constructing the earth stations and scored outstanding successes by emancipating their minds and following China's own road of developing science and technology.

CSO: 5500

ANTICORRUPTION REPORT NOTES SEIZURE OF RADIO TRANSMITTERS

Bangkok NATION REVIEW in English 9 Nov 77 pp 1, 3 BK

[Excerpt] Thirty-five persons have been arrested in a series of raids on clandestine radio-transmitting stations in the northeast and Bangkok "where Vietnamese were found to have illegally directed radio programmes in collusion from some government officials."

Anti-corruption committee [ACC] Secretary General Suthi Akatsoloek reported yesterday that in coordinated raids against the illegal radio stations in the northeast, authorities seized 15 10-kilowatt radio transmitters, 2 1-kilowatt transmitters and 1 20-watt transmitter, valued at 25 million baht.

Two clandestine radio stations were raided in Bangkok, he said. Mr Suthi said the raids were part of the coordinated work of ACC officials working hand in hand with the customs, public relations, police and post and telegraph departments.

He did not specify the period of time during which the raids were carried out but the ACC secretary general said the activities were part of the annual report filed by the ACC to the Revolutionary Party.

The annual report, covering the period from 1 October, last year until 30 September 1977, also says that the ACC had also assisted in discovering corrupt forestry officials in the past year.

CSO: 5500

SRV RADIO, TV COMMISSION HOLDS CONFERENCE IN HO CHI MINH CITY

Ho Chi Minh City Domestic Service in Vietnamese 2345 GMT 8 Nov 77 BK

[Text] On 8 November in Ho Chi Minh City, the Vietnam Radio and Television Commission opened the first conference on broadcasting and wired radio activities in the southern provinces. Attending the conference were representatives of people's committees and of propaganda and training departments of provincial party committees. Also present were cadres in charge of radio and television stations in the southern provinces.

Comrade Tran Lam, alternate member of the party Central Committee and chairman of the Vietnam Radio and Television Commission, reported on the situation and duties of the local radio broadcasting and wired radio networks. After pointing out the great achievements of the broadcasting and wired radio networks over the past 30 years, he talked about the duties and functions of the Radio and Television Commission and about the present broadcasting and wired radio task.

The political task of the Radio Broadcasting and Television Network is essentially the political task of the press organs aimed at contributing to the propaganda, education, motivation and organization of the masses and to the transformation of the party's resolutions into the mass revolutionary action movement. Today, although most radio broadcasting stations and the local wired radio network have just been built, the radio broadcasting and wired radio task has enjoyed fundamental advantages. The radio broadcasting and wired radio networks have been entrusted by the party and state with a glorious political task and a worthy role in socialist construction. They have been provided with fairly good material and technical means and cadres and have acquired much experience serving as a basis for further progress.

The conference heard a draft report on the functions, duties and organization of the body managing the local radio broadcasting and wired radio network and of organs in the southern provinces responsible for assisting the Vietnam Radio and Television Commission in the radio broadcasting and wired radio activities.

The conference will work for 3 days.

CSO: 5500

BULGARIA

BRIEFS

RADIOELECTRONICS SYMPOSIUM--Varna, 2 Nov (BTA)--The 6th Symposium on Radioelectronics with the participation of scientists and experts from Bulgaria, the GDR, Poland, the Soviet Union, Hungary, Czechoslovakia, Austria and Finland began here today. The participants will discuss questions concerning the design, technology and [word indistinct] in radio location, radio navigation and radio relay lines and the possibilities for rapid and effective solving of problems arising in the radioelectronic industry. [Text] [Sofia BTA in English 1437 GMT 2 Nov 77 AU]

CSO: 5500

CZECHOSLOVAKIA

BRIEFS

NEW TV TRANSMITTER--A new television transmitter for the second program was put into operation at Tlusta Hora near Gottwaldov today. [Prague MLADA FRONTA in Czech 28 Oct 77 p 2 AU]

CSO: 5500

BRIEFS

UNDERSEA CABLE--The General Public Committee of the Communications Secretariate approved the budget for the building of an undersea cable between Tripoli and Benghazi. This budget is estimated at 10.485 million Libyan dinars. This project is considered to be one of the largest being executed by the Post and Telecommunications Corporation during the current plan. It is being executed by an international company and has a capacity of 900 telephone and telecommunication channels with special two-way channels for radio and television. The importance of this project is the fact that it is a successful and practical replacement for the existing centimetric waves from Tripoli to Benghazi. The project will be ready for operation according to the most modern international specifications 2 years from now. The company building the project will be in charge of training a sufficient number of nationals to operate the project, in addition to that company's responsibility to carry out all maintenance work for a period of 2 years after the completion of the project. [Text] [Tripoli AL-FAJR AL-JADID in Arabic 3 Oct 77 p 1] 8988

CSO: 5500

BRIEFS

NEW RADIO TRANSMITTERS--Two new radio transmitters are being built at al-Hiswah, a 200 kW mediumwave transmitter and a 100 kW shortwave transmitter. Radio transmission via the 200 kW transmitter is expected to begin on 30 November, during our celebrations of the 10th anniversary of national independence. [Aden Domestic Service in Arabic 1230 GMT 3 Nov 77]

CSO: 5500

UGANDA

BRIEFS

LIVE TELEVISION--Uganda television's outside broadcasting unit is already in Nile Province on test transmission starting today up to Sunday daily at 2030 hours. Uganda television will telecast live the laying of the foundation stone of Uganda earth satellite station at Urua and the opening of the OAU Ministers of Information Conference on Monday, 7 November. The telecast will be for Uganda as well as any other countries interested in receiving it. [Text] [Kampala Domestic Service in English 1700 GMT 4 Nov 77 LD/EA]

CSO: 5500

BRIEFS

KHURMULI-BEREZOVYY RADIO LINE--Workers of the eastern section of the Baykal-Amur railway report that the Khurmuli-Berezovyy radio relay line has been put into operation, making it possible for residents of remote settlements in Solnechnyy Rayon such as Perezovyy, (Obolin) and Duki to watch central television programs. Their first television program was a direct relay from Moscow of the joint solemn meeting devoted to the 60th October Revolution anniversary. [Khabarovsk Domestic Service in Russian 0930 GMT 5 Nov 77 OW]

SEVERO-KURILSK ORBITAL STATION--Another orbital station has been put into operation in Severo-Kurilsk, which made it possible for thousands of its residents to watch the festivities in Moscow. [Vladivostok Maritime Service in Russian to the Pacific Far East 0700 GMT 6 Nov 77 OW]

CSO: 5500

USE OF E10 SWITCHING SYSTEM IN TANDEM OFFICES VIEWED

Paris L'ECHO DES RECHERCHES in French Apr 77 pp 4-11

[Article by Jean-Pierre Coudreuse, telecommunications engineer, head of Electronic Systems Experimentation Department (RCI-ESE [Integrated Switching Research-Electronic Systems Experimentation]) of the National Center for Telecommunications Study (CNET) in Lannion, and Jean-Claude Faure, senior inspector in the same department: "The E10 System in Tandem Offices"]

> [Text] It was initially determined that the E10 system's most favorable sphere of employment was in providing automatic dial service in areas with a low density of telephones. The system has now also proved to be highly suitable for handling local exchange areas equipped with SOCOTEL [Joint Company for Development of Telecommunications Switching Techniques] automatic switching systems nearing the saturation point. Using the Rennes installation as an example, the following article describes the E10's "pure tandem" utilization from the standpoint of its specific aspects that differ from a toll center equipped with E10 time-division switching equipment.

The E10 time-division switching system has previously been amply described in this review, both with reference to its principle as well as to its initial applications in toll centers, switching centers, or in the switching of leased-line networks.

Although providing dial service in local exchange areas with low telephone density was initially a suitable sphere of utilization for the E10 system, another economically warranted application of time-division switching is now the handling of SOCOTEL type electromechanical minor exchanges nearing saturation in areas already converted to dial operations. Such handling is generally concomitant with the installation of trunks connected directly to the E10 tandem office as soon as that office is established. Such handling eventually involves replacing all SOCOTEL minor exchanges with E10 connecting units. However, a "pure E10 tandem office" operation was established in Rennes.

Hence this article discusses solely those characteristics specific to the operation of an E10 automatic time-division switching system serving as a tandem office: connecting distant subscribers through satellite equipment (either a SOCOTEL minor exchange already in operation or a distant connecting unit of the E10 type); development of these satellites for expansion of saturated SOCOTEL's, initially by parallel operation and then by replacing existing electromechanical equipment without major modification of the basic plant.

Connecting SOCOTEL equipment into an E10 tandem office raises a certain number of technical questions related to operations: billing SOCOTEL subscribers, testing local circuits, connecting test boards and transmission measuring sets to a pure tandem office, modification of connecting-equipment programs and boards. The readings from peg count registers shown in this article were obtained in early 1976 with very reduced programs. Complete load observation programs are currently underway in some tandem offices.

Lastly, the example of the Rennes-Lavoisier tandem office, whose evolution is characteristic of this type of application, is described in detail.

Use of the E10 System in Local Exchange Areas

Distant Subscriber Connecting Units

The possibility of establishing satellite exchanges by means of subscriber connecting units (URA) identical to those used locally for servicing central office subscribers, gives the E10 system the dual capability of being suitable for establishing subscriber loops designed to service rural or suburban areas. In fact, recourse to distant "concentrators" is almost a necessity in scattered networks, instead of multiplying, at a prohibitive cost, the number of inordinately low-capacity independent-routing exchanges. It should also be noted that this remote siting in no way alters the possibilities of connecting cross-connecting terminals (TELIC), PBX lines, Telex lines, or any other equipment that can be connected into a subscriber connecting unit.

Moreover, systematic utilization of digital transmission between the core of the E10 time-division chain and the URA carries at URA level all of the volume equivalent available for the terminal system: the only restriction limiting the length of the subscriber line is, therefore, generally the minimal amount of power (or current) supply consistent with efficient operation of the URA's calling equipment (or subscriber line). This amount of current is presently on the order of 15 milliamperes. Use of dipoles of the Calliope type or of intensity correctors for telephones with low current consumption is also still possible under the same conditions as with electromechanical equipment.

Lastly, introduction of remote concentration substantially reduces distribution costs.

Remote or distant URA differs from local URA by the contents of its stored program and by the addition of supplemental program cards designed chiefly for transmitting signaling information via the semaphore channel and for synchronizing the URA with the tempo of the digital link. Within a period of time much shorter than the service life of installed equipment, a satellite exchange sometime becomes large enough to warrant converting it into an independent-routing exchange. This situation is frequently noted in some fast growing suburban areas. In such cases, use of standard equipment permits converting the exchange with a minimum of disturbance to both equipment and users. In fact, conversion of a distant URA into a local URA merely requires substitution of a few program cards.

Connecting SOCOTEL Minor Exchanges

Local trunks running into minor exchanges are connected in the same way as interoffice circuits or short-haul toll circuits, namely via a Multiplex Synchronization Module (MSM).

If the link is made digital by means of the TNE [Terminal Numerical Equipment (?)] terminal equipment in the minor exchange, the connection of each 30-channel multiplex is made directly, the remote power supply equipment being preferably within the MSM so as to facilitate maintenance. Of course, if the length of the link warrants, it may be necessary to provide a remote power supply unit at each end of the link.

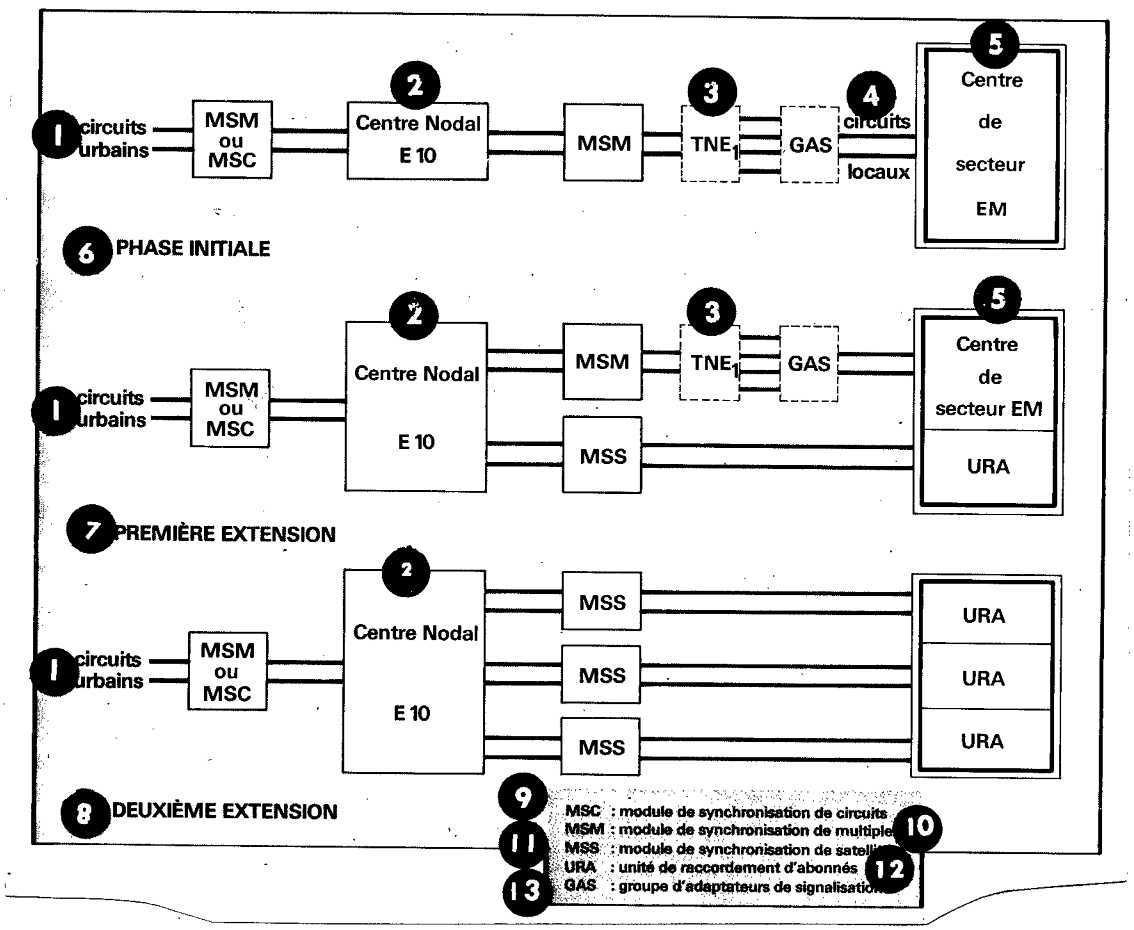
When the link is worked at low frequency the connection of each trunk is made on a signal converter coupled to a TNE installed in the E10 exchange. The code most generally used is the SOCOTEL pulse code. The only type of converter developed is a converter for low-level 50 Hz pulses. There are two versions of this converter, one for outgoing circuits, the other for incoming circuits. The essential difference between these two versions is that the latter has a filter designed to suppress the 50 Hz parasitic frequency detrimental to telephone calls. To facilitate adjustment and maintenance, the ringing or signaling set used on the E10 converter is identical to the one used in the minor exchange's SOCOTEL junctor.

Expansion of E10 Tandem Office for SOCOTEL Minor Exchanges

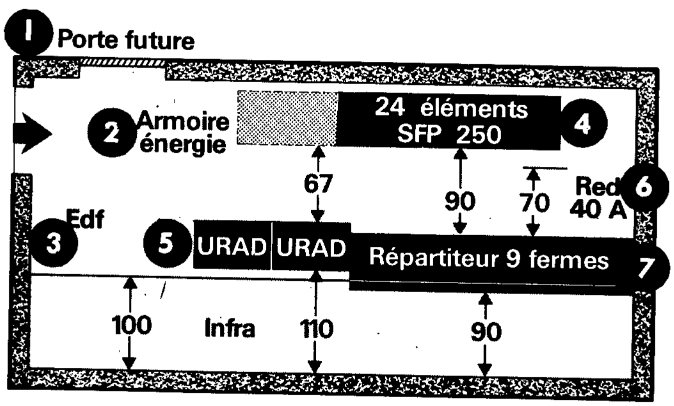
The E10 system uses two-way communications called "networks-lines" to tie URA's and Circuit Connecting Units (URC's) into the connecting network, without special assignment to one or the other function. Hence if a subscriber loop is initially planned to serve solely electromechanical minor exchanges, it is perfectly conceivable--in a first phase--to add URA's to it so as to expand certain minor exchanges, and then--in a second phase--make further expansion by replacing electromechanical frames with new URA's. Control devices contain programs common to all types of subscriber loops, thus making it possible to carry out these operations without doing anything to the control devices, except possibly to insert supplemental program parameters defining the added

equipment. To attain maximum capacity in the second phase, it may be necessary to replace URC's of the MSM type with URC's of the MSS (Satellite Synchronization Module) type.

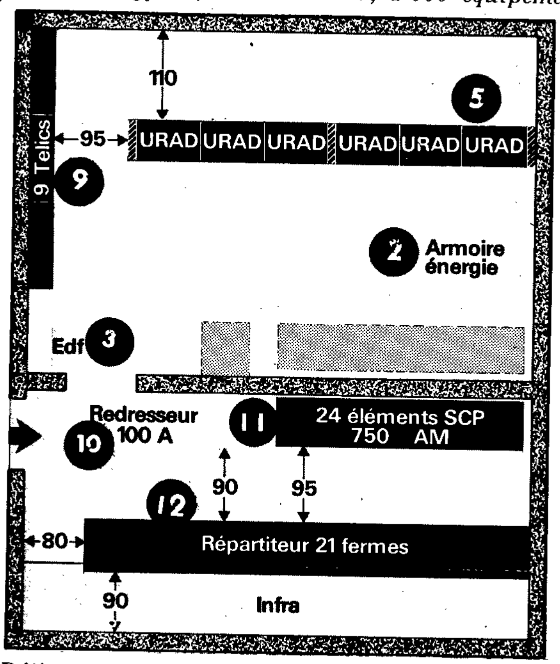
Different Phases in Expansion of Minor Exchange



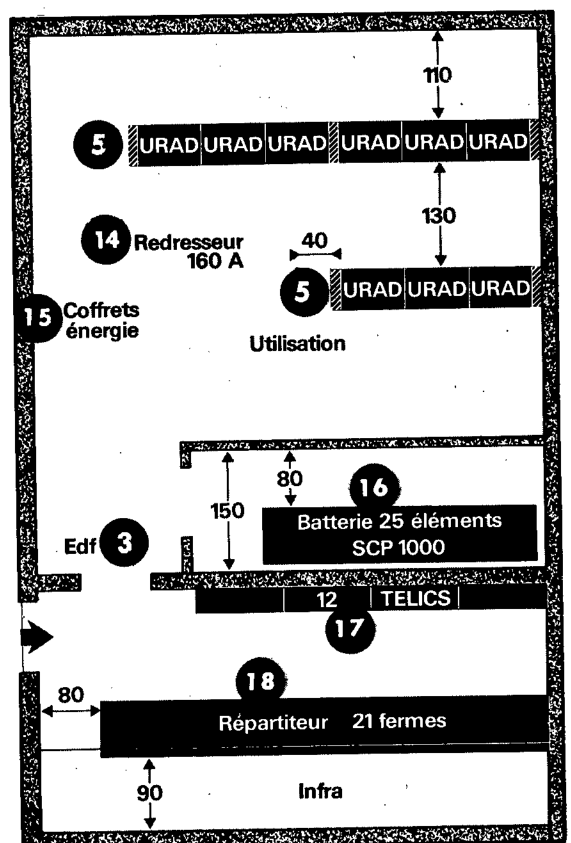
Key:
1. Interoffice trunks
2. E10 tandem office
3. Terminal Numerical (Digital) Equipment
4. Local circuits
5. Electromechanical minor exchange
6. Initial phase
7. First expansion
8. Second expansion
9. MSC: Circuit Synchronization Module
10. MSM: Multiplex Synchronization Module
11. MSS: Satellite Synchronization Module
12. URA: Subscriber Connecting Unit.
13. GAS: Signal Converter Group



8 *Bâtiment type I, satellite E 10, 1 000 équipements*



13 *Bâtiment type II, satellite E 10, 3 000 équipements*



19 *Bâtiment type III, satellite E 10, 4 500 équipements*

Key:

1. Future door
2. Power panel
3. French Electric Power Company
4. 24-cell battery SFP [expansion unknown] 250
5. Distant Subscriber Connecting Unit.
6. 40-ampere rectifier
7. 9-bay distributing frame
8. Type 1 building, E10 satellite, 1,000 subscriber lines
9. 9 cross-connecting terminals
10. 100-ampere rectifier
11. 24-cell battery SCP [expansion unknown] 750 AM
12. 21-bay distributing frame
13. Type 2 building, E10 satellite, 3,000 subscriber lines
14. 160-ampere rectifier
15. Power units
16. 25-cell battery SCP 1000
17. 12 cross-connecting terminals
18. 21-bay distributing frame
19. Type 3 building, E10 satellite, 4,500 subscriber lines.

On the other hand, transforming a distant URA into a local URA, or vice versa, requires substantial modification of the program. The use of reprogramable stored programs makes it possible to change the program quite simply by rewriting the contents of the REPROM unit or by replacing program storage cards with cards programed beforehand by means of a MACHPRO.

Connecting Test Boards and Transmission Measuring Sets

Since a tandem office does not necessarily have local subscriber connecting units it was not possible to connect devices working in Subscriber code directly to the office. Hence a special adapter was developed for connecting onto the MSM--through the TNE and signal converter--a two-wire line worked in Subscriber code. Prototypes were used for the first time in the Rennes E10 tandem office. Regular production models reemploy the battery supply circuit designed for the junctor cards (JCA) of the subscriber space concentrator (CSA).

Testing Local Circuits

The large number of circuits connected to a tandem office warrants installation of a test board (or wire chief's desk) facilitating the adjustment of circuits worked by signaling at 50 Hz pulses. However, such installation is not absolutely necessary if there is a large percentage of digital (numerical) circuits. The present test board was developed on request of the Regional Telecommunications Directorate of Rennes because of the entirely analog environment of the tandem office at the time it was put into service. The board had two simulating devices, one generating signals transmitted by the tandem office, the other generating signals trnasmitted by the minor exchange. Measuring instruments are used to check exchanged alternating voltages and to measure distortions of the code pulses. These checks and measurements are made on calls initiated by the operator from the test board. For this purpose, the board is linked to a circuit by a cord plugged into a connector on the band of the signal converter serving the circuit to be tested.

Traffic Observation Results

Prior to the introduction of complete load and traffic observation programs, a series of hourly readings were taken at the Poitiers E10 toll office for a period of 7 full but nonconsecutive days. Results obtained cover a total of about 600,000 calls and were obtained entirely from the control element's six peg count registers during the different reading periods.

At the time of these readings, the E10 office was equipped to handle approximately 13,300 subscribers. It was, therefore, quite near its maximum capacity in cross-connection boxes.

The following table and two charts summarize the results of these readings: distribution of incoming calls, outgoing calls, and local calls, ratio of completed calls, etc.

Removal of the electromechanical frames can be facilitated by using special trailers as satellite exchanges, thereby permitting 2,000 subscribers to be connected into four remote URA's. Each of these trailers actually consists of a 9 meter by 2.4 meter container or van that can be carried on the bed of a semitrailer and loaded or unloaded by a "dumpster" type device on the flatbed. Three other trailers have been designed along the same lines. One includes a chain core for 840 circuits and 8,000 distant subscribers. The second is a van housing the power supply unit for this chain core. The third is an Information Processing Center (CTI) equipped with a Mitra 125 computer. All of this equipment will be available for use in late 1977 and should, therefore, permit not only replacement of saturated SOCOTEL minor exchanges but also their attached tandem offices frequently consisting of R6 equipment.

In a building standardized to house a minor exchange-type 1, 2, or 3, for example--maximum expansion capabilities depend on the SOCOTEL equipment existing at the time the E10 system is installed, and also on the capacity of the distributing frame and power supply unit. The following three sketches depict the possible positioning of E10 equipment in these buildings after complete removal of the electromechanical equipment.

Operating Characteristics

Charging (Billing)

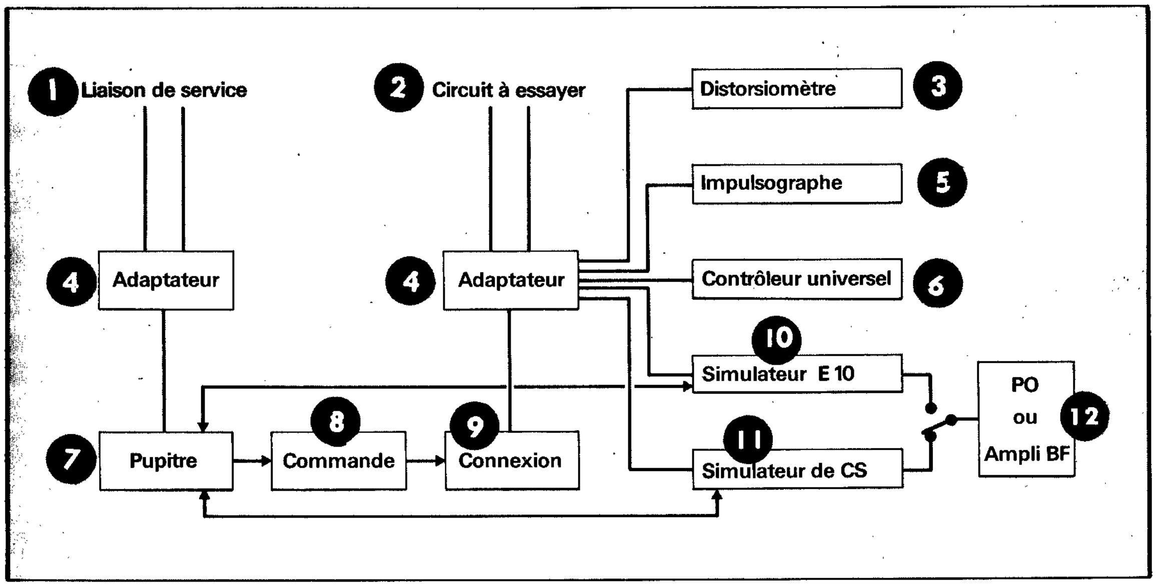
Connecting minor exchanges to an E10 exchange necessitates transferring charging pulses onto local connecting circuits. Consequently these circuits must be equipped with a TLT (Teletaxe [Telecharge]) discriminator at translator level. For each call, other than those worked locally in the minor exchange, the customary recording of a charging word is concomitant with the recording of a word from a secondary storage of the charger unit. This second word contains the coordinates of the circuit utilized--the number of the selection channel and the number of the time channel--,thereby enabling the charger unit to transmit, via a special link, a "calibration" at 128 milliseconds of the charging pulse pertaining to this circuit. This calibration is accomplished by sending a "transmit" message followed by a "stop transmitting" message.

Modification of Programs and Boards

In normal operations there are no such modifications on the URC's [Circuit Connecting Units] except when carrying out correction orders. Any modification in the nature of the connected circuits--change in code, modification of the trunk groups--is made in the translator's lines and on a specific board (or desk) of the Multiplex Synchronization Group (GSM) called Multiplex Signaling Board (TSM). The TSM card is now made in the form of a reprogramable and easily changeable SITTER card.

The storage part of this card is in duplicate, thus permitting modification of the parameters of one trunk group without disturbing the handling of other trunk groups connected via the same GSM.

General Schematic of Test Board for Local Circuits



Key:

1. Service line
2. Circuit to be tested
3. Distortion meter
4. Adapter (converter)
5. Pulse analyzer
6. Universal controller
7. Console
8. Control
9. Connection
10. E10 simulator
11. Minor exchange simulator
12. Pulsed oscillator (?) or low-frequency amplifier

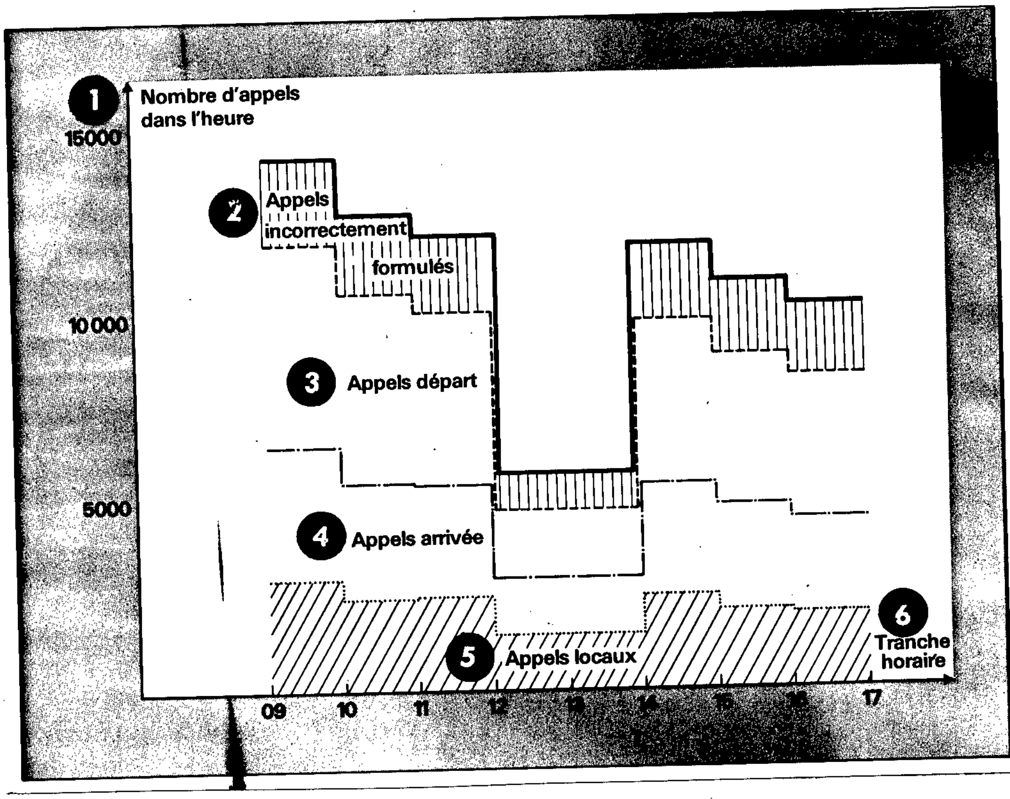
Significance of Control Element's Peg Count Registers

C1: New "confirmed" calls
C2: Completed calls
C3: Completed calls to local subscriber
C4: Correctly dialed calls)
C5: Calls to local subscriber) After translation of routing
C6: Local calls)

C5-C6	: Incoming calls
C4-C5	: Outgoing calls
$C6 \times \frac{C3}{C5}$	: Completed local calls*
$(C5-C6) \times \frac{C3}{C5}$	: Completed local calls*
C2-C3	: Completed outgoing calls
$(C2-C3) + C6 \times \frac{C3}{C5}$	: Billed calls*

*The percentage of completed calls made to local subscriber is determined for local and incoming calls simultaneously.

Breakdown by number of calls handled (average hourly values)

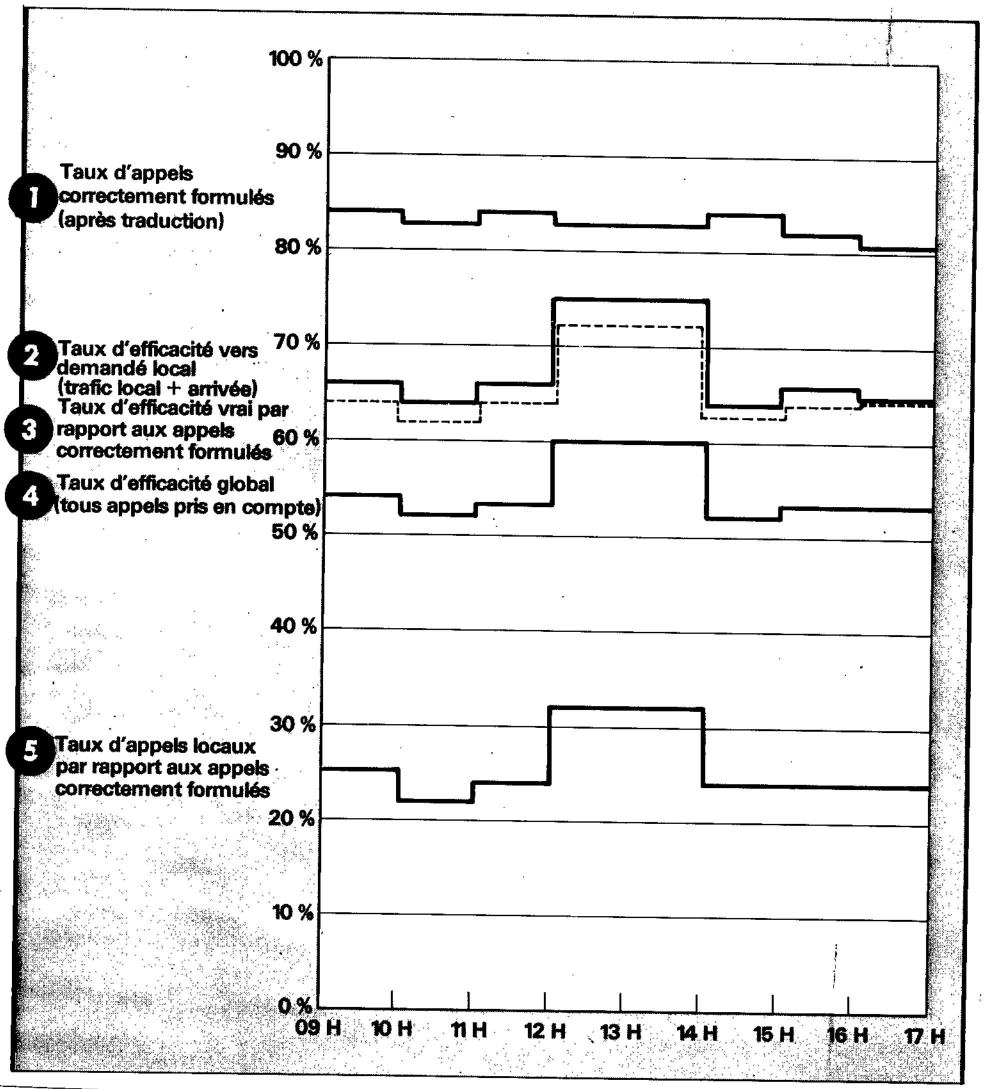


Key:
1. Number of calls in the hour
2. Incorrectly-dialed calls
3. Outgoing calls
4. Incoming calls
5. Local calls
6. Hourly cross-section

Rennes-Lavoisier Tandem Office

This office became operational on 27 March 1975. It was the first E10 exchange to serve as a tandem office. Equipment installed at that time permitted connecting 440 local low-frequency circuits worked in SOCOTEL code. Since then, that number has risen to 800, including 180 digital circuits (6 MIC [expansion unknown] systems). Subscribers connected in this way total 8,100 distributed over 12 SOCOTEL exchanges. At the same time, approximately 2,000 subscribers distributed over six E10 concentrators of the CSA (Space-Time Concentrator for Subscribers) type were also connected. This number will be increased to 9,500 over 20 CSA's in October 1977. The office's load will then be 18,500 subscribers, 540 long-distance dialing circuits, and 630 interoffice circuits (including 360 digital circuits).

Certain average hourly ratios and percentages



Key:
1. Percentage of correctly dialed calls (after translation)
2. Percentage of completed calls made to local subscriber (local traffic + incoming traffic)
3. Real ratio of completed calls to correctly dialed calls.
4. Overall percentage of completed calls (all calls considered)
5. Ratio of completed local calls to correctly dialed calls.

It should be noted that no special program was written for this office which strictly uses the same programs as provincial toll offices (type B program). Inasmuch as traffic handling capacities of electromechanical minor exchanges will ultimately be insufficient, this use of nonspecific programs will be such as to facilitate their replacement by E10 type Subscriber Connecting Units.

Future Developments

With 56 connected Selection Units (US) and about 18,000 subscribers, the Rennes tandem office will reach its maximum capacity in October 1977. A plan for completely equipping the suburban area with E10 systems has been prepared because subscriber connection requirements are expected to become even much greater in the outskirts of the city.

A second office, Rennes-Bru, was therefore inserted in the 1976 program. It will relieve the Lavoisier office without, however being connected to SOCOTEL exchanges. Lastly, two other short-haul toll (suburban) units are, in principle, to be included in the 1978 program, one designed to serve the eastern area, the other the western area. The R6 tandem office, into which 12 minor exchanges are still connected, should disappear about 1980. Electromagnetic equipment in these exchanges is to be replaced gradually, with the first of these operations scheduled for June 1977: because the E10 satellite-trailer is not yet completed, subscribers will be changed over to a SOCOTEL trailer, and then changed over once more to the E10 equipment installed as replacement for the SOCOTEL equipment.

Lastly, it should be pointed out that almost all interoffice trunks connected to E10 centers will become digital between now and 1979.

Conclusion

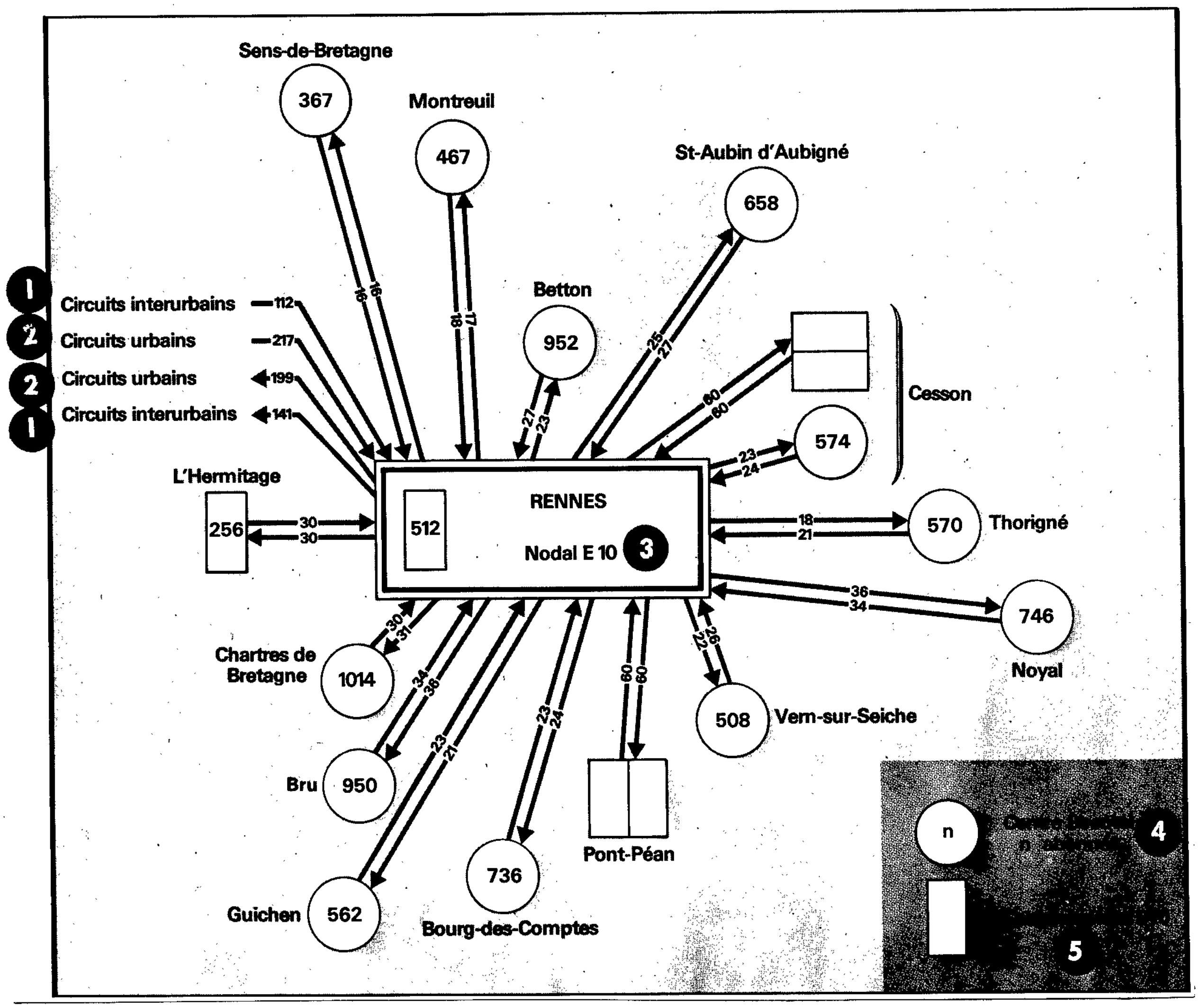
The two complementary methods of connecting distant subscribers--takeover of the SOCOTEL exchanges and employment of distant connecting units--appear simultaneously more often than not as soon as a new E10 automatic switching system is installed. This tandem function we have just described may also coexist perfectly--without any modification of the chain core--with an interoffice function of connecting local subscribers.

The technical flexibility thus provided by the E10 system with respect to methods of connecting subscribers also makes it possible to eventually convert satellites initially made up of distant connecting units into Independent Routing Exchanges (CAA). This technical flexibility has a corollary financial flexibility as far as capital spending is concerned. In fact, such investments can be better staggered because areas that would have had to be equipped with a CAA space-division switching system can be temporarily served by distant connecting units until their expansion warrants the presence of a chain core.

Furthermore, thanks to the savings achieved in connecting distant subscribers, juxtaposition of the tandem and local interoffice functions will make it possible to show a positive balance sheet in some cases, even if local service area subscribers still currently cost more compared with other systems.

The broad sphere of employment thus described is currently favorable to the E10 system. A few examples of the facilities either under construction or planned include: toll offices in the Paris regional Area No 2 (Luzarches and Villepreux), tandem offices in the 1976 program (Quimper, Toulon, Lorient) or in the 1977 program (Rouen, Dreux). The first application of the E10 automatic switching system to 129 selection units of double the capacity of standard E10 exchanges, will also be of the tandem type and installed in Brest.

Rennes tandem office as of 1 May 1977



Key: 1. Toll circuits
2. Interoffice trunks
3. E10 tandem office
4. SOCOTEL exchanges; n = number of subscribers
5. E10 concentrator

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FRANCE

GROWTH OF CADUCEE TELEPROCESSING NETWORK REVIEWED

Paris L'ECHO DES RECHERCHES in French Apr 77 pp 22-31

[Article by Alain Dupont, senior telecommunications engineer in the Distribution, Terminals, and Services Division of the National Center for Telecommunications Studies (CNET) in Issy-les-Moulineaux, and Dominique Gerard-Hirne, engineer in the CNET's Department of Data Transmission and Private Systems (RTS-TOP [Systems, Terminals, and Service-Data Transmission and Private Systems] in Issy-les-Moulineaux: "Caducee Traffic After 4 Years of Operations"]

> [Text] After 4 years of operation, the Caducee network appears to have basically satisfied the demand for data transmission service and justified the technological choice its adoption constituted. The authors of the article below analyze the latest available traffic observations. Their analysis is based on criteria similar to those employed for the telephone system. After comparing these observations with initial estimates, they highlight different types of calls, peak traffic loads, dispersion of the duration of calls, and the importance of certain geographical regions.

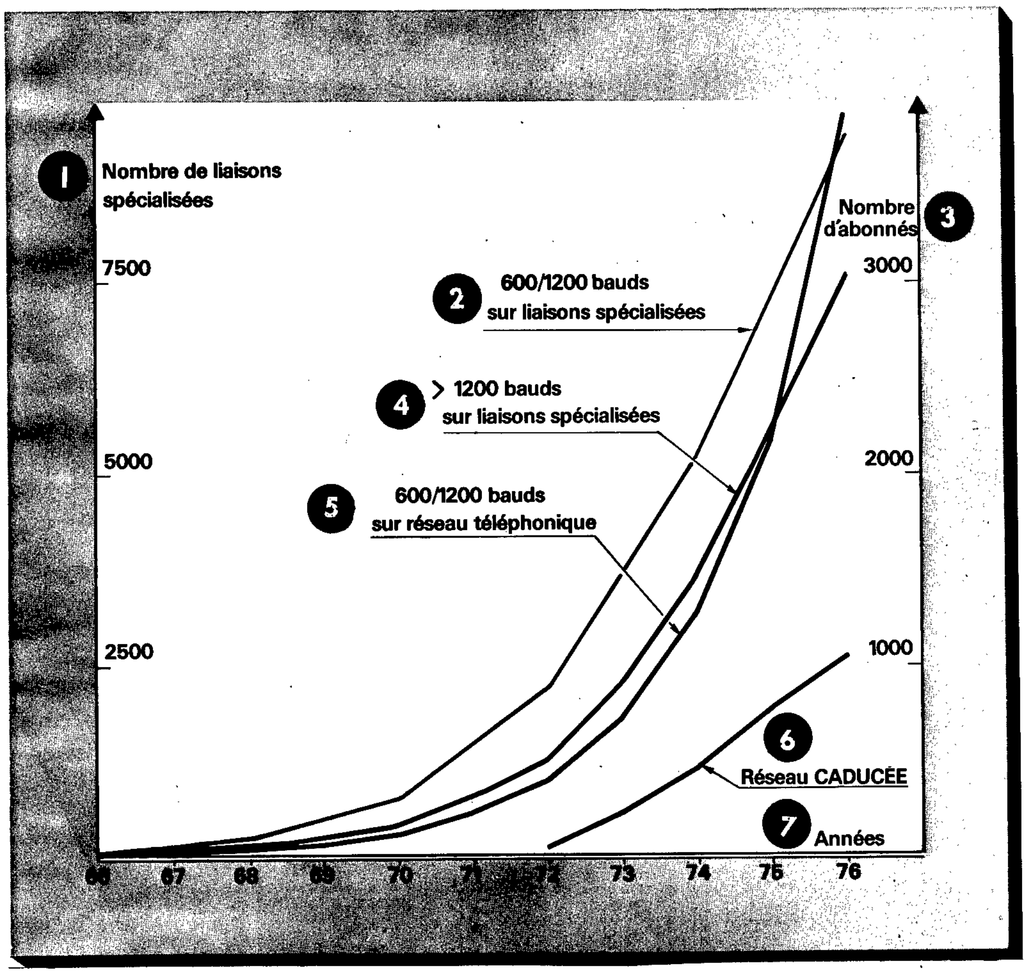
Caducee Network

The Caducee switching network was conceived back in 1969 and installed in 1972. It was designed to meet a three-point goal: fill the gaps in teleprocessing services provided by PTT's [Postal, Telegraph, and Telephone Service], experiment by developing a full-scale teleprocessing system, and orient data processing equipment manufacturers and users toward systematic use of a public switching network specifically adapted to their requirements. This network and its innovative features have already been thoroughly described on several occasions. Its main components have also been discussed in various publications: terminal facilities, line concentrators, maintenance of local loops and automatic switching equipment. Although this was a revolutionary system in many respects, it was meant to be only a transitional but long-lasting phase prior to introduction of the digital switching network fully adapted to high-speed data transmission, namely the Hermes network.

Caducee subscribers have been increasing at a rate of nearly 300 per year. The resultant total of more than 1,000 subscribers at the end of 1976 thus confirmed estimates made in 1970 and warranted the installation of a second automatic switching facility in Lyon in the near future. Lyon is France's second leading data processing center after Paris.

Caducee's rate of growth may appear rather slow in comparison with the much more rapid increase in the number of leased-line networks at 600-12,00 bauds, at more than 1,200 bauds, or subscribers to data transmission at 600-1,200 bauds over the telephone switching network.

Increase in number of leased-line networks and connections made into the telephone network and Caducee network.



Key:

1. Number of leased-line networks
2. 600-1,200 bauds over leased-line networks
3. Number of subscribers
4. > 1,200 bauds over leased-line networks
5. 600-1,200 bauds over telephone network
6. Caducee network
7. Years

However the Caducee network can actually meet only part of the demand because of its analog character and electromechanical automatic switching equipment. It also demanded a new standardization effort on the part of automatic data processing equipment manufacturers. Lastly, its growth could not help but be limited on account of its single connecting point despite the development of concentrators that made it possible to connect 60 percent of the network's subscribers from outside the Paris region, mainly from Lille, Lyon, and Marseille.

Importance of Traffic Analysis

Several reasons make traffic analysis of the Caducee system extremely valuable. At the time the system was designed and put into operation, teleprocessing traffic over a specialized switching network was absolutely unknown. Hence it is essential to determine the characteristics of such traffic, not only in preparation for the future Hermes network, but also so as to be able to compare these characteristics with those of telephone traffic as much as possible. To draw any valid conclusions from this analysis it was definitely necessary to wait until the promotional period had passed, because the interest incited during that period might give a false picture of the real requirements. It was also necessary to wait until the number of subscribers became significant, so that the number of test calls would be small in relation to the real traffic. These considerations account for the relatively long period of time that has elapsed between the date the system became operational and the writing of this article. Yet Caducee traffic was observed throughout these 4 years and showed a steady change, particularly in the now-stabilized duration of calls.

A feasibility survey made among major users and maufacturers in 1969 disclosed traffic characteristics based exclusively on flows between computer and terminals, assuming that the rates fixed did not favor certain categories of transactions. This led to an average call duration of about 1 minute which was unacceptable for the electromechanical type of automatic switching equipment. To prompt users to plan longer calls, a handling charge was established for a call lasting about 1 minute. The following table shows the characteristics of the estimated traffic.

In fact, as we shall see, these fears were not confirmed because the duration of calls proved to be much longer than estimated. They were about 10 minutes long in 1973 and have now stabilized at approximately 7 minutes. One plausible explanation: users quite frequently chose the Caducee network for relatively low-speed purposes instead of the telephone system, probably because it was much less congested and more error-free.

Hence it is highly useful to compare the findings of this analysis with corresponding results of a telephone traffic analysis, notably peak hours, distribution of calls by duration, and their type and number. An original feature of the Caducee system should be noted at this point: it is possible for the called subscriber not to answer the call, even when he is not busy. This case, called "unavailableness" is designed to cover computer maintenance time and is

Estimates made in 1969 of Caducee network subscriber traffic

[redacted]	1 Charge prévue après tarification				
	2 Terminaux			5 Moyenne pour les terminaux	6 Ordinateurs
	3 dialogue		4 lourds		
	a	b			
Nombre en % 7	22	11	52		15
Nombre d'appels à l'heure ch concernant un terminal 8	7	15	1	44	20
Durée d'un échange 9	75 s	36 s	300 s	90 s	90 s
Trafic par terminal à l'heure ch 10	0,15 E	0,15 E	0,08 E	0,11	0,5 E

Key:
1. Expected load after setting rates
2. Terminals
3. Dialog
4. Heavy
5. Average for terminals
6. Computers
7. Number in percentage
8. Number of busy-hour calls for one terminal
9. Duration of one call
10. Traffic per terminal in busy hour

a. Consolidated-traffic terminals
b. Nonconsolidated-traffic terminals

tantamount somewhat to the "no answer" in telephony. However, in such cases the Caducee system's calling party is informed of this unavailableness situation, a procedure that should reduce the number of uncompleted calls. The traffic billing and observation system installed back in 1972 analyzes all calls, completed or not, thus giving detailed information, the equivalent of which is difficult to obtain in telephony.

Lastly, the traffic flow between the various subscribers is important from two standpoints: the distribution between light-traffic and heavy-traffic subscribers shows specifically that calls between light-traffic subscribers (terminals) are much more numerous than had been estimated. Geographical distribution of the flow is most important, if only as a means of anticipating the network's future development, but also as an indication of the teleprocessing situation in the various regions. Some regions actually have relations practically only with the Paris region, while others have a real local flow of traffic.

A few main characteristics determined from all the calls made during a 7-week period in October-November 1976 are shown in the table below.

General characteristics of Caducee network traffic during the period October-November 1976

	Busy-hour average: Total/completed	Daily average: Total/completed
Number of calls		
-Working days	1117/506	8058/4598
-Busy days	1367/579	9300/4940
Average duration of calls in minutes		
-Working days	/6.7	/6.9
-Busy days		/7.2
Traffic by hours		
-Working days	/56	/526
-Busy days		/604
Number of calls per subscriber	0.56	
-Outgoing or mixed		
Traffic per type of subscriber		
-Ordinary 93.5 percent	0.10E	
-Heavy outgoing traffic 0.5 percent	0.04E	
-Heavy incoming traffic 6 percent	0.24E	

Traffic per ordinary subscriber fully corresponds to the initial estimates. The distribution of this traffic does not, however. These subscribers communicate chiefly with each other and very little with the so-called "heavy incoming-traffic" subscribers. This situation explains to a great extent the fact that the latter's traffic is less than had been estimated. It also is reflected in the breakdown by number of calls.

Variations in Traffic During the Week

Examination of the sample observations of 4 weeks in October 1976 reveals that traffic is concentrated within the 5 first working days of the week: an average of 8,000 calls daily and about 520 hours of communications were recorded. Saturday traffic is comparatively very light. It represents only 6 percent of the number of calls and 11 percent of the average traffic on the other working days. Sunday traffic is practically negligible despite the special low rates on that day: 0.16 percent of the number of calls and 0.4 percent of the traffic on working days.

Yet we noted that completed calls last 15 minutes on Saturday and 17 minutes on Sunday (versus nearly 7 minutes on working days). Traffic on those days probably flows into heavy incoming-traffic subscribers, i.e. into computers.

The distribution of traffic over the 5 working days is practically uniform. A very slight peak in traffic is noted on Wednesday with 22 percent of the weekly calls handled on that day compared with 19 to 20 percent on other days. The distribution of traffic by percentage is about the same except on Monday which accounts for only 17 percent of the average traffic, but this irregularity seems to be merely transitory.

Hourly Distribution of Traffic

Traffic on working days is distributed mainly between 0800 and 1900. A total of 17,345 hours of traffic were observed during the 33 working days in the period of 20 October to 19 November 1976. Some 86 percent, or 15,017 hours, of this traffic was handled between 0800 and 1900. The graph below of the hourly distribution of traffic over 10 busy days shows how the average traffic and number of calls remain concomitant and undergo the same variations except during reduced-rate hours.

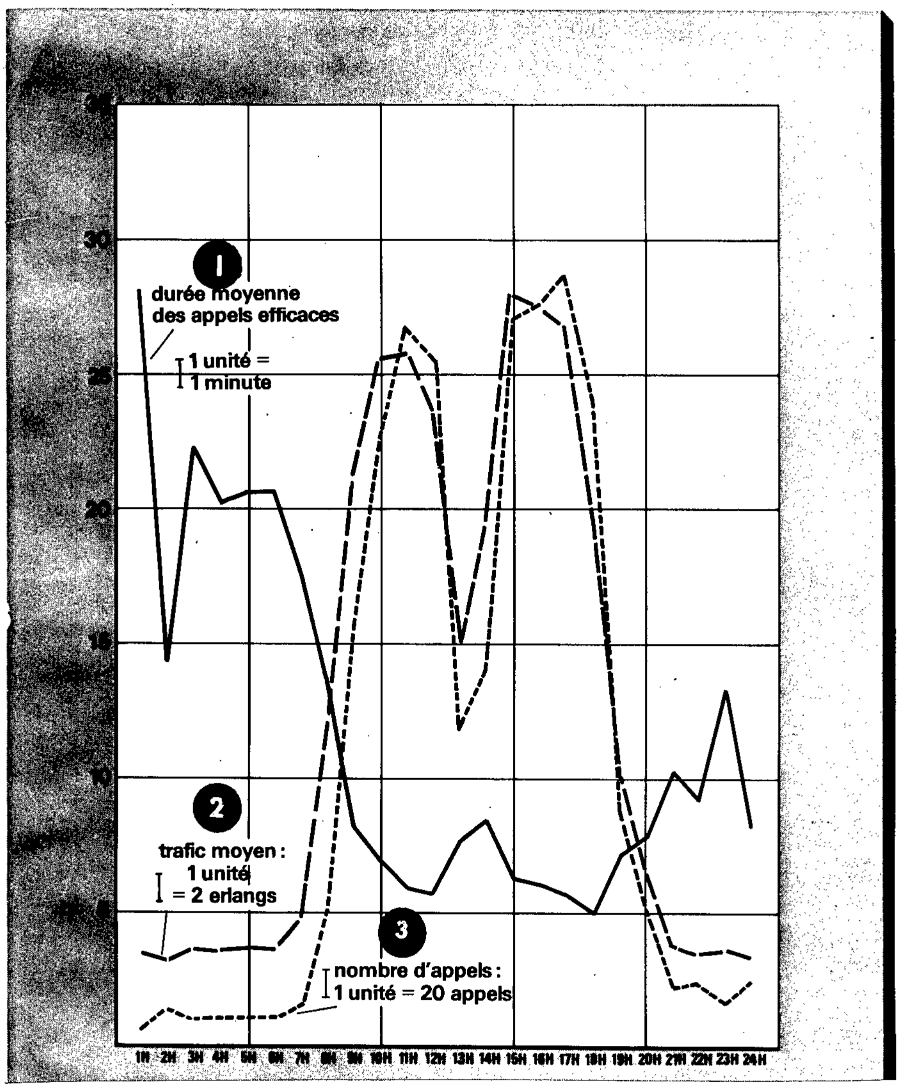
For the latter, we note a longer duration of calls, hence the greater impact of one call on the hourly traffic. For instance, the average duration of calls is 6.5 minutes between 0800 and 1900, 9.6 minutes between 1900 and 2400, 21 minutes between 0000 and 0600 hours, and 15.6 minutes between 0600 and 0800. These readings were taken over 10 days in which an unusually large number of calls were made.

Busy or peak hours are between 1000 and 1200 and 1400 and 1800. The graph below shows a lower percentage of completed calls for these same hours. Furthermore, generally speaking, the greater the number of calls the lower the percentage of completed calls. It is important to underscore this outcome because this situation can only be attributed to the subscribers, given the relatively small load of the present central office and the singleness of that office.

Various Types of Calls

The number of calls per day and per subscriber is 8.5 versus 1.2 per busy hours. The corresponding number of completed calls is 4.8 and 0.55 respectively. This means the percentage of completed calls is 57 on the average and 46 for the busy hour. Other types of calls are mainly those that are not completed because the lines are busy or the called subscriber is unavailable. As the table below shows, the percentage of these two types of uncompleted calls is about the same.

Hourly distribution of traffic over 10 busy days, of hourly completed traffic, of average duration of completed calls, and of number of completed calls.

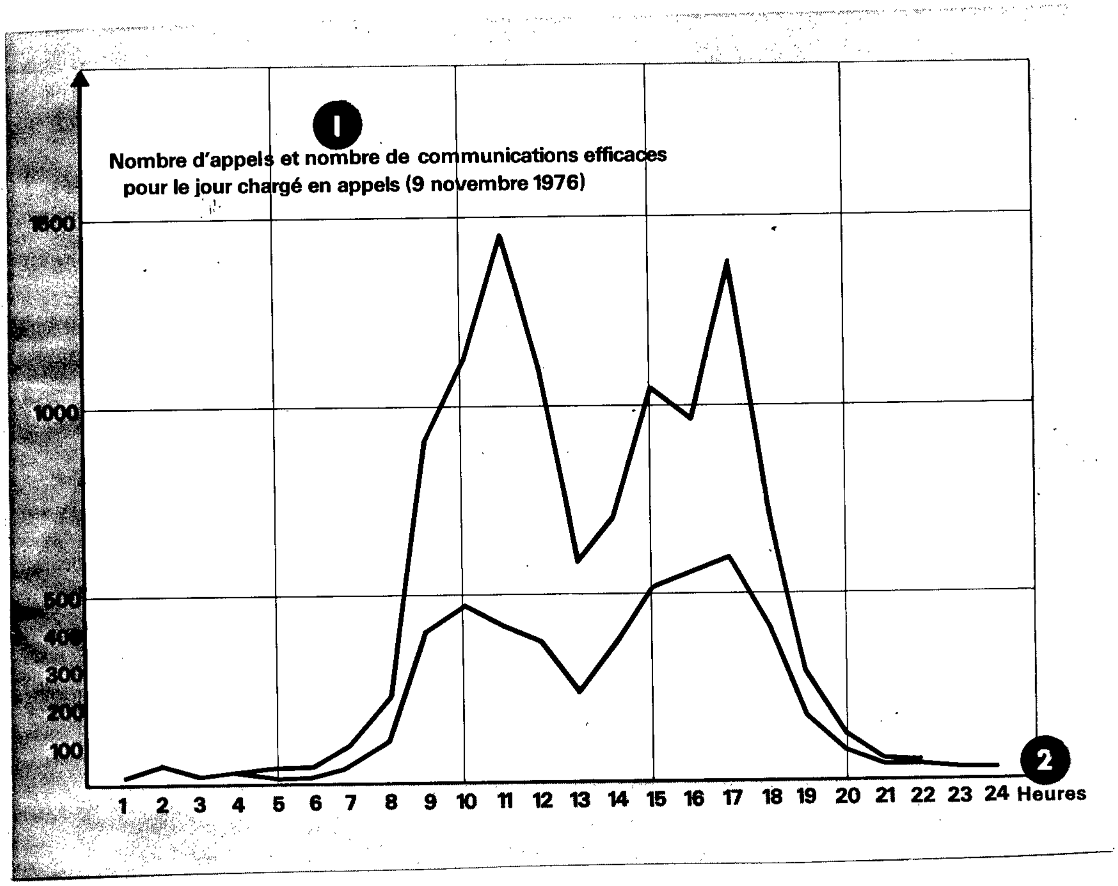


Key: 1. Average duration of completed calls: 1 unit = 1 minute
2. Average traffic: 1 unit = 2 erlangs [Erlangian distribution]
3. Number of calls: 1 unit = 20 calls.

Daily distribution, during a busy hour, of calls as a function of outcome of calls

Outcome of call	Number of calls per per day in %	Number of busy-hour calls, in %
Line busy	20.4	28
Unavailableness	20.8	22.5
Completed	57.1	46
Miscellaneous	1.7	3.5

Hourly variations in number of completed calls



Key: 1. Number of calls and number of completed calls for a day with an unusually large number of calls (9 November 1976). 2. Hours.

We notice that there are very few reputed wrong numbers or incomplete numbers upon translation, and it is interesting to compare these percentages with those of telephone calls, it being understood, of course, that the equivalence which seems to exist between the unavailableness of a Caducee network subscriber and the no-answer of the telephone system's called subscriber is only apparent. A survey made in early 1975 in the Marseille area covering more than 50,000 national telephone calls furnishes some indication of the percentages of completed calls, and uncompleted calls for "line busy" and "no answer" reasons: approximately 42 percent, 49 percent, and 9 percent respectively. However the "line busy" calls include those uncompleted because of subscriber error as well as those uncompleted because of telephone system congestion. Consequently there is no possible correspondence between these results and results observed on the nonsaturated Caducee network and its single central office. An approximation consists in taking the average percentage of "line busy" telephone calls and deducting therefrom that percentage due to system congestion and then excluding the corresponding calls. In this way, we obtain a new distribution of calls in which completed calls are certainly overestimated in relation to the real percentage and "line busy" calls are underestimated. Thus we find: 63.5 percent (completed calls), 23 percent (uncompleted because of line busy), and 13.5 percent (uncompleted because of no answer). This distribution would correspond, therefore, to the distribution in a "fluid" network for national calls (excluding local and regional calls).

Comparison with Caducee thus basically shows a lesser percentage of completion for Caducee calls and a corollary higher percentage of uncompleted calls for reason of subscriber "unavailableness." This characteristic actually needs to be verified by more accurate measurements on the telephone network.

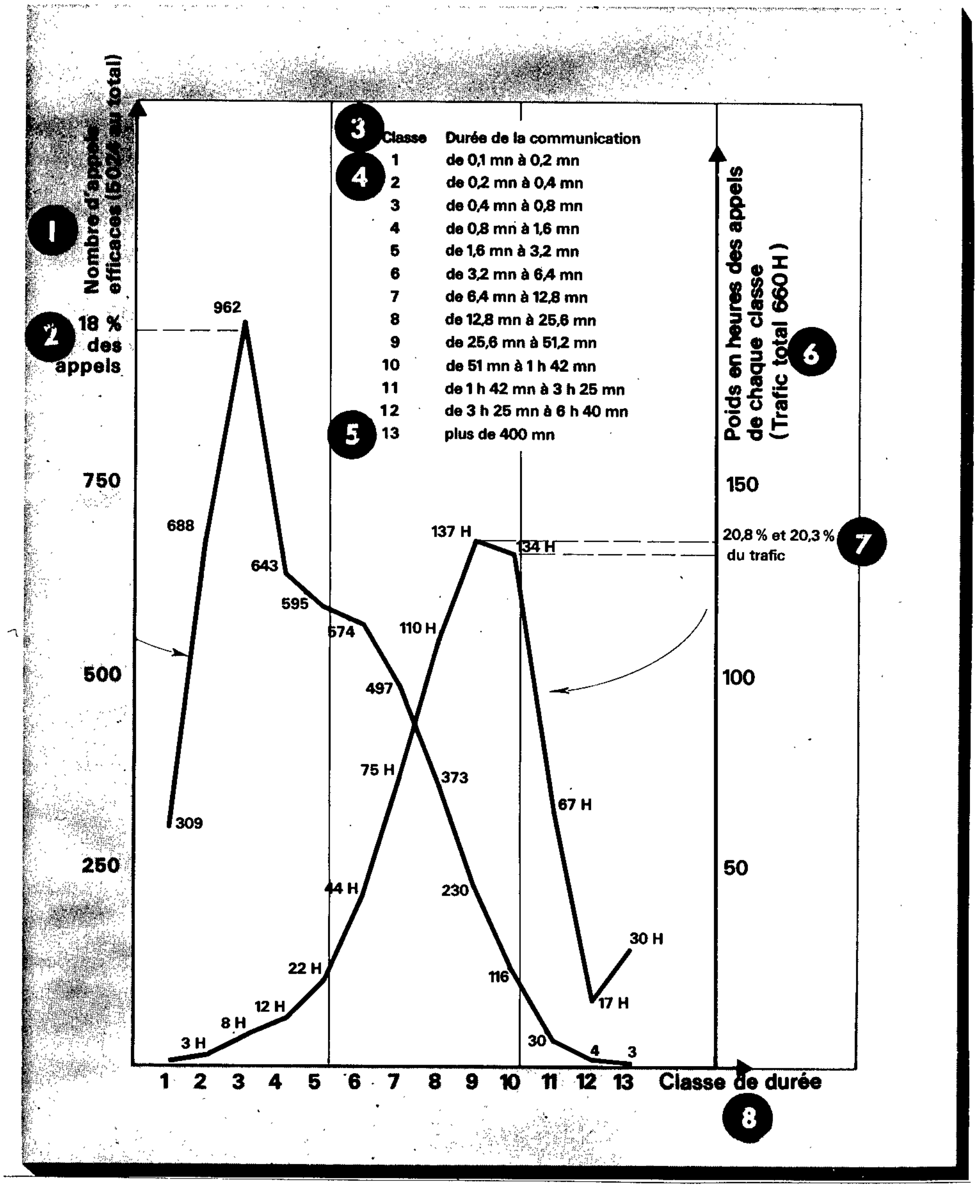
Duration of Calls

All calls were broken down into 13 classes of duration. These classes in geometric progression range from 0.1 to 400 minutes, thus enabling us to detail the distribution of short-duration calls and take into account the very long calls that have a very great impact on overall traffic.

Estimates made prior to installation of the Caducee network indicated a distribution of calls in classes 3, 4, and 6 representing traffic emanating from terminals of the electromechanical type from terminals with cathode ray tube display, and from heavy terminals respectively. It was estimated that class 3 would account for 45 percent of the calls and 18 percent of the traffic, class 4 for 41 percent of the calls and 35 percent of the traffic, and class 6 for 14 percent and 47 percent respectively.

Yet as shown in the graph below, classes 1 to 4 actually account for only 52 percent of the calls (instead of 86 percent) and less than 4 percent of the traffic.

Distribution of calls by duration for the day (6 October 1976) with the heaviest traffic.



Key:
1. Number of completed calls (Total: 5,024)
2. 18 percent of calls
3. Class Duration of call
4. From 0.1 minute to 0.2 minute
5. More than 400 minutes
6. Load by hours of calls in each class (Total traffic: 660 hours)
7. 20.8 percent and 20.3 percent of traffic
8. Class of duration of call

Classes 1 to 7 cover approximately one fourth of the hours of call while they account for 85 percent of the number of calls. This distribution peculiarity had already been noted during the initial observations and this distribution pattern has remained constant. Classes 9 and 10 have also continued to produce the traffic peaks.

The graph below furnishes a comparison of telephone calls (sampling in December 1975 of 6,672 daytime calls to all destinations), "visiophonic" calls (sampling of 553 calls in second 4 months of 1975), and Caducee network calls in October-November 1976. We chose Gaussian coordinates indicating percentages of the cumulative number of calls (ordinate) and percentages of the cumulative duration of these calls (abscissa), because they furnish straight lines roughly parallel to the first bisector and quite easy to compare, even though very close to each other. In fact, the closer the straight line is to the vertical axes, the greater the dispersion, and a good characterization is furnished by the point of intersection with the second diagonal; thus we find:

a. For the telephone calls considered: 71-29

b. For the "visiophonic" calls: 76-24

c. For the Caducee calls: 81-19

These figures can be read as follows: for the Caducee network, 81 percent of the calls (of shortest duration) correspond to only 19 percent of the total charged duration (or time), and inversely, 81 percent of the total charged duration corresponds to only 19 percent of the calls.

This large dispersion of Caducee network calls is definitely confirmed by the limiting values of durations indicated along the curves: from 5 percent to 85 percent for the number of calls, these durations range:

a. From 1 minute to 1 hour 50 minutes for Caducee,

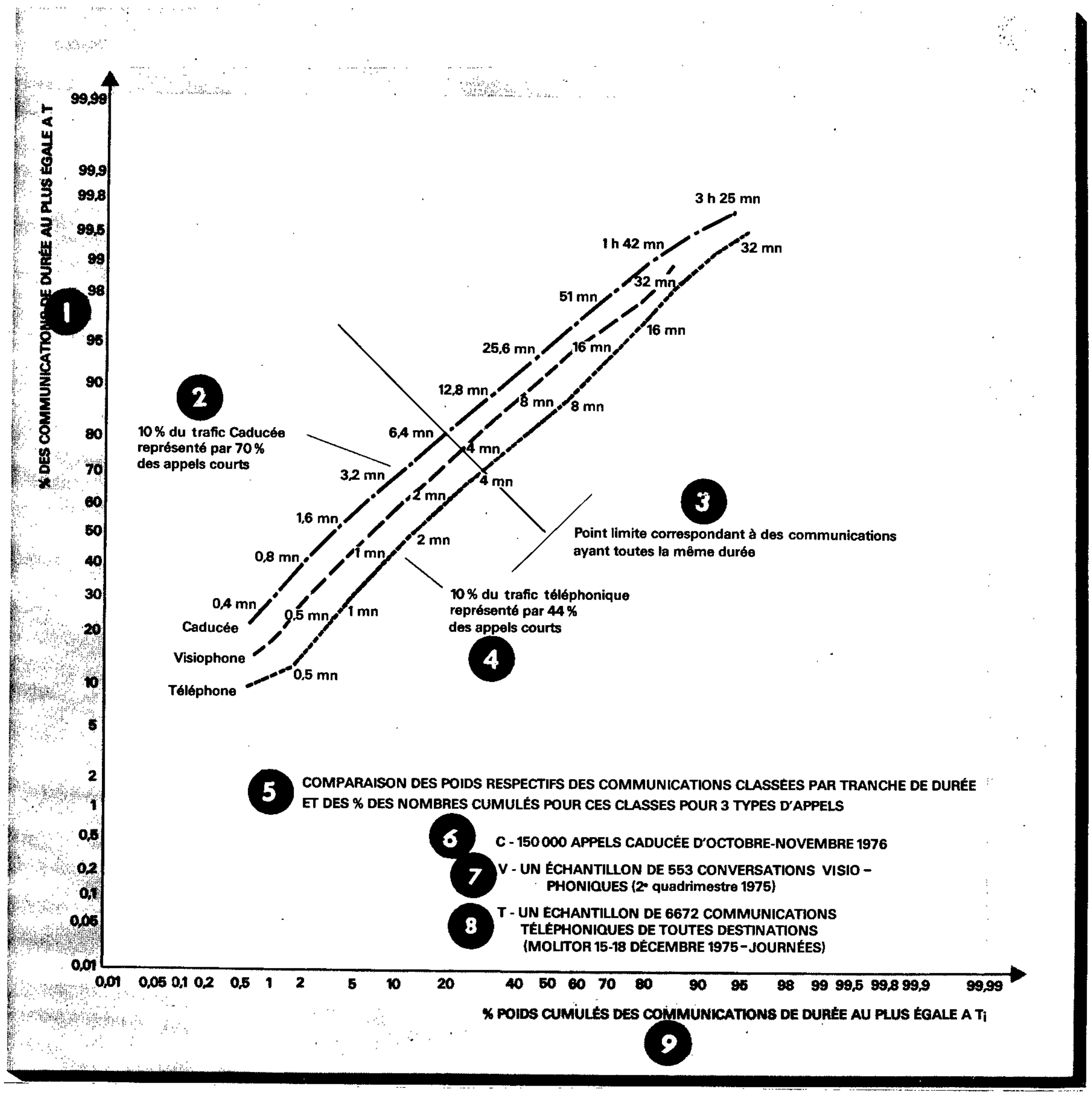
b. From 1 minute to 40 minutes for the "visiophone,"

c. From 1 minute to 20 minutes for the telephone.

Traffic Between Different Types of Subscribers

Busy-hour analysis shows that estimates made prior to installation of the Caducee network have far from materialized. First of all, as we saw earlier, the distribution of subscribers by classes of traffic is not the one expected: 93.5 percent of ordinary or "light-traffic" subscribers instead of the estimated 85 percent. Furthermore, 73.5 percent of busy-hour traffic is ascribable to calls between ordinary subscribers, 26 percent to calls from ordinary subscriber to "heavy incoming traffic" subscriber, while other possible calls account for only 0.5 percent of the total flow. A review of the number of calls leads to the same conclusions for the period surveyed: of 269,910 calls recorded, 58,684, or 21.7 percent of the total, were to "heavy incoming traffic" subscribers.

Comparison of Caducee, Visiophone, and Telephone



Key:

1. Percentage of calls of duration equal to T at most
2. 10 percent of Caducee traffic represented by 70 percent of short calls
3. Limiting point corresponding to calls all of the same duration
4. 10 percent of telephone traffic represented by 44 percent of short calls
5. Comparison of respective weights of communications classified by duration and of percentages of cumulative numbers for these classes for three types of calls.
6. C - 150,000 Caducee calls in October-November 1976
7. V - a sampling of 553 visiophonic calls (second 4 months of 1975
8. T - a sampling of 6,672 telephone calls to all destinations (Molitor [Paris exchange], 15-18 December 1975-daytime calls)
9. Percentage of cumulative weights of calls of duration equal to T, at most.

Geographical Distribution

Some 41 percent of the subscribers are in the Paris region and 59 percent in other regions. This breakdown closely tallies with initial estimates. In contrast, the traffic is noticeably different. It was estimated traffic would be mainly within the Paris region (65 percent) and from the provinces into Paris (30 percent). In actuality, it is distributed as follows: 24 percent within the Paris region, 36 percent from other regions into Paris, 18 percent from Paris into other regions, and 22 percent between other regions. We note a balance between the Parisian traffic and traffic of other regions, plus the existence of appreciable traffic from Paris into the provinces, though twice less than traffic in the opposite direction. This demonstrates that the network is truly national despite the existence of only a single automatic switching system in Paris. It is, therefore, important to take a closer look at the principal regional characteristics: the number of subscribers, outgoing traffic, incoming traffic, and internal traffic. The Paris inner-city region is, of course, altogether exceptional with 39 percent of the subscribers, very heavy internal traffic, and a very sharp imbalance in favor of incoming traffic over outgoing traffic.

Of the 21 delimited regions, we shall dispense with considering six that have an insufficient number of subscribers. It is no surprise that three regions--Lyon, Lille, and Marseille--each have 7 to 8 percent of the subscribers. Five regions--Bordeaux, Nancy, Orleans, Rouen, and Toulouse--each have nearly 4 percent, while the seven others each have between 1.5 and 3 percent.

Lille has very substantial internal traffic: more than three calls per subscriber per day. Marseille and suburban Paris have 4 times less calls per subscriber. Lastly, Lyon, Bordeaux, Strasbourg, and Rouen have significant internal traffic: 20 times less calls per subscriber than Lille.

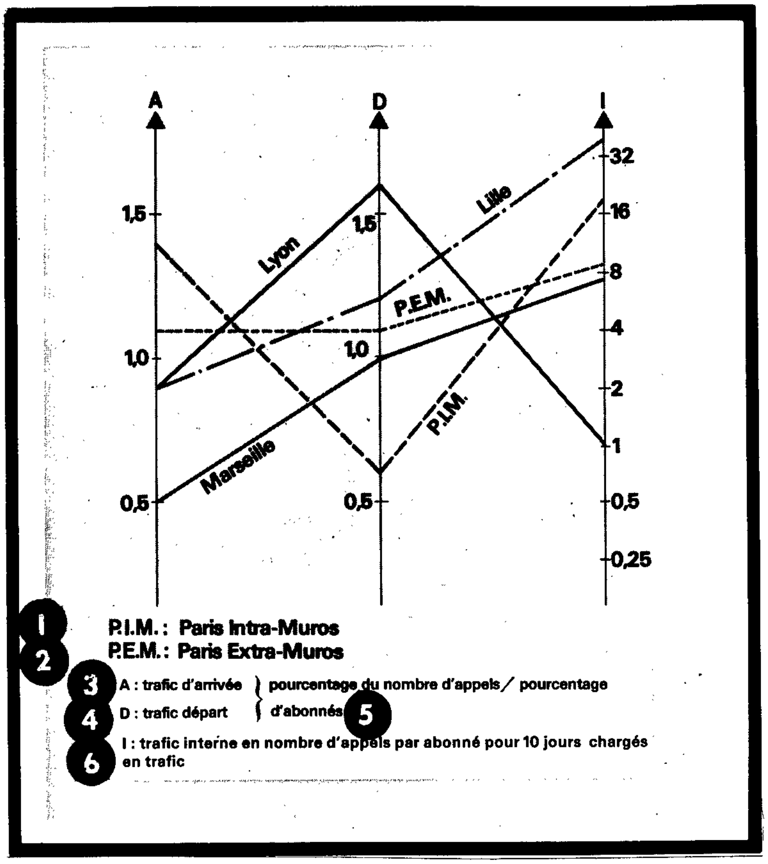
If for each region, we establish the ratio between the percentage of traffic (outgoing and incoming) and the region's percentage of subscribers, we bring out four principal categories of regions:

a. Regions with "normal" traffic, i.e. ratios close to unity: Lille and suburban Paris. These two regions are clearly in a class apart: Lille because it has very heavy internal traffic and suburban Paris because of its geographical location;

b. Regions with normal incoming traffic and heavy outgoing traffic: Lyon, Nantes, and Nancy;

c. Regions with light incoming traffic and normal outgoing traffic: Marseille, Bordeaux, Strasbourg, Rouen--all having normal internal traffic--Rouen, and Toulouse;

Principal characteristics of the following regions: inner-city Paris, suburban Paris, Lille, Lyon, and Marseille



Key:

1. PIM: inner-city Paris
2. PEM: suburban Paris
3. A: incoming traffic
4. D: outgoing traffic
5. Percentage of number of calls over percentage of subscribers.
6. I: internal traffic by number of calls per subscriber for 10 heavy-traffic days.

d. Satellite regions with characteristics the opposite of Paris characteristics (light incoming traffic, heavy outgoing traffic, and no internal traffic): Clermont-Ferrand, Grenoble, and Nice.

Lastly, Orleans is somewhat apart, having light traffic (outgoing or incoming) and zero internal traffic.

It may be of interest to compare the table below giving percentages of inter-regional traffic with the estimated table for the Transmic network: a few slight differences appear, in addition to the existence of internal traffic.

1 MATRICE INTERRÉGIONALE DE TRAFIC EN POURCENTAGE

	Amiens	Bordeaux	Châlons	Clermont-Ferrand	Dijon	Lille	Limoges	Lyon	Marseille	Montpellier	Nancy	Nantes	Orléans	Poitiers	Rennes	Rouen	Strasbourg	Toulouse	Grenoble	Nice	Paris Extra-Muros + Intra-Muros (2)
Amiens					0,2	0,4			0,2									0,3	0,3		
Bordeaux		0,2	0,1						0,1										0,2		3,8
Châlons					0,1	0,2		0,1				0,1	0,1						0,1		1,3
Clermont-Ferrand						0,1		1,1													0,8
Dijon								0,4			0,2					0,1					0,6
Lille						5,2		1,1	0,1		2,3	0,4	0,1			0,3	0,2				5,7
Limoges																		0,2			0,3
Lyon								0,1	0,2		1,2		0,4				0,9		2,5	0,2	8,1
Marseille									1,1	0,3			0,2					0,2		0,1	7,1
Montpellier																					0,7
Nancy													0,7			0,1	0,2				3,6
Nantes													0,1	0,2		0,2		0,1			5,4
Orléans														0,5							2,5
Poitiers																			0,2		0,2
Rennes																0,1					2,6
Rouen																0,3		0,1			2,7
Strasbourg																	0,3	0,1			2,4
Toulouse																					1,9
Grenoble																					1,9
Nice																					1,7
Paris Intra-Muros + Paris Extra-Muros (2)																					21,4

3 Moyenne sur 10 jours chargés

Key: 1. Interregional Traffic Matrix, in Percentage
2. Suburban Paris + Inner-city Paris
3. Average over 10 busy days.

Conclusion

Thanks to an advanced traffic observation system, we were able to obtain accurate and extremely valuable information on traffic heretofore unknown (data transmission over a switched network specifically designed for this purpose), whereas corresponding information on telephone networks is barely beginning to be analyzed. The most striking fact is unquestionably the large dispersion of the duration of calls around an average duration substantially greater than had been estimated.

Now that this traffic is quite well known, we will have to even further extend the comparison with telephone traffic once accurate information is available. We will also have to begin making such comparison with Transpac and Transmic traffic and try to deduce therefrom the basic characteristics to be taken into consideration for the possible Hermes network.

8041
CSO: 5500

FRANCE

BRIEFS

STOLEN BROADCAST EQUIPMENT--There has been an increase in thefts at the television broadcast and relay stations administered by Tele-diffusion de France [Television Broadcast Network of France]. The police suspect the leftist, ecologist and autonomist groups in the country of wanting to equip their pirate stations at low cost and then have them begin broadcasting during the electoral campaign. [Text] [Paris LE POINT in French 31 Oct 77 p 69]

CSO: 5500

ECONOMIC EVALUATION OF TELECOMMUNICATIONS SYSTEMS

Milan ALTA FREQUENZA in English No 2, Feb 77 pp 2-10E

[Article by Giovanni B. Stracca (Socio AEI) - Istituto di Elettrotecnica ed Elettronica, Politecnico di Milano. Work done at Centro Onde Millimetriche of Fondazione Ugo Bordoni, under the agreement with the Istituto Superiore P.T.]

[Text]

Comparison of telecommunication systems requires the consideration of an enormous number of technical and economic factors. Economic comparisons are generally based on cost valuation methods such as PVE (Present Value of Expenditures), AC (Annual Costs) or PVAC (Present Value of Annual Costs); the choice among them depends on the type of problem to be studied. Their use may present in some cases a number of disadvantages, which are discussed in the paper. A different approach is analyzed in the paper, which refers to a cost/utility ratio as a figure of merit. In evaluating this figure the cost is defined as the present value of weighted annual costs, i.e. as if the annual costs were distributed along the life of the systems in a mathematically equivalent way with the same law as the annual utility of the system.

Some examples are given to compare in some idealized cases this method with the PVAC method.

1. - Foreword.

The choice between alternative telecommunications systems depends on various factors and characteristics of the systems (cost, technical features, maintanance, reliability, existing facilities, etc.). Although the economic factors are not the only ones, which are to be considered, they pay surely an important role on the choice of the system.

Economic comparisons are generally based on well known cost evaluation methods, such as the Present Value (or Worth) of Expenditures (PVE), the Annual Costs (AC) or the Present Value (or Worth) of Annual Costs (PVAC). These three basic forms of cost studies are mathematically equivalent [1] and the choice among them depends on the type of problem to be studied, as discussed in sect. 4, or also on personal preference. In some cases however their use does not seem to be satisfactory for an economic comparison among different transmission systems, as in the case of comparison among very large transmission systems which will be available in next future; for example circular waveguide systems (with a two way capacity in the range between 150 000 to 500 000 telephone circuits), multitube coaxial cable carrier systems (with one way capacity per tube between 10 800 to 30 000 telephone channels) or satellite communication regional systems.

(1) For example a traffic expansion in Europe or in Italy is expected to be of the order of 100 000 or 150 000 equivalent telephone circuits on the main routes in a period of time between the next 10 to 15 years with a typical annual increment rate of about 10% to 20%.

An economic comparison among these systems could be meaningless, if limited to cost analysis only, because their service capability or utilization time, as well as the investment costs or distributed investment costs can be very different. The large capacity operation, offered by these systems, may be gradually utilized only in many years, if installed in next future in Italy or generally in European countries, by considering the present traffic situation on the main transmission routes and the forecasts of traffic expansion (1). The difficulties to make forecasts of technological advances, which may occur during the long expected life of the plant and, perhaps, before the utilization of its whole service capability, and of their impact on future costs, make it very difficult to evaluate the expenditures for the parts of the plant which should be installed too far in the future, as well as the expenditures for the replacements. It is even more difficult to forecast the cost of future plants to be installed on a given transmission route either when the system under evaluation will no longer provide the service demand expansion or at the end of its life.

Because it is not possible to extend the costs and the service demand expansion forecasts up too far in the future and therefore up to the time $t = \infty$, it is necessary to limit the cost comparison to a convenient period of time (called the « study period »), which should be short enough to make acceptable forecasts. As discussed in the following sect. 4, the economic comparison between different systems does not seem in this case to be performed satisfactorily on the basis of the various methods, previously quoted, because generally it is not made on the basis of an equivalent overall service capability and/or of an equivalent service capability at the end of the « study period ». It is therefore necessary to take into account also the evaluation of the different service capabilities and of the different services (or of what will be called here system « utility »), provided by different systems along the study period.

Purpose of this paper is therefore to discuss (sect. 5) a temptative study form to compare different systems, which takes into account both cost and utility forecasts in the limited « study period », where forecasts are still reasonable.

The basic premises to be considered for said study form are discussed in sect. 2, while a tentative definition of the system « utility » is given in sect. 3. An analyis of available study forms, based on costs only, is discussed in sect. 4. Examples of economic comparisons among different systems, using both the study form discussed in sect. 5 and other study forms, are given in sect. 6.

2. - Basic premises for an economic study form to compare different transmission systems.

A study form for an economic comparison of different transmission systems should satisfy some general basic premises, on which a general agreement could be found. It seems that these premises could be the following:

a) The comparison should take into account the service demand forecast over a given transmission route in a period of time long enough to be meaningful, but not too long to avoid forecasts extended too far in the future (for example the period could be typically 10 to 15 years and not greater than 20 years).

b) The cost evaluation should take into account the timing of expenditures and retirements (2) (which are generally different for different systems) by converting expenditures at different dates to an equivalent amount at a common date.

(2) Some investements occur at the beginning of the plant life, as those for the transmission medium (i.e. those for cables or waveguides and their installation, for trenching and conduits, land, accessory equipment for pressurization, etc., buildings-including ancillary services and purchase or leasing of land for the stations).

Other investements occur at future dates. For example those for the repeater equipment and their installation, as well as those for the terminal equipment, are distributed along the life of the plant depending on the growing of the service demand. Also the operation costs are distributed annually along the life of the plant and are growing with the service demand.

The costs for repeater equipment are those for the transmitting and receiving equipment and ancillary facilities installed both in the intermediate and in the terminal stations of radio links or of waveguide systems and those of the line amplifiers in cable systems (including their installation). The costs of terminal equipment are those of multiplex equipment installed in terminal stations and of their ancillary equipment for switching, control alarms and protection.

c) Only the expenditures made in a limited period of time, the « study period » (for example in a period smaller than 20 years) should be considered in the cost evaluation. This is due to the fact that cost forecasts on the basis of a given technology cannot be reasonably extended to all the plant life, because technological improvements may modify equipment and change their costs, may render obsolete the system configuration under evaluation and allow the introduction of new more advanced systems over the same transmission medium.

d) The life of the equipment is generally smaller than that of the transmission medium. Because of the technological advances the equipment may be considered obsolete after about 15 years, according to the present experience. The operational life of the transmission medium is much longer than the « study period » previously defined, for example 40 to 50 years.

e) In the comparison among different systems the right importance should be given to the fact that over a given route some of the systems may offer a service capability larger than that required or forecast at a given future date (for example after 10 or 15 years or at the end of the « study period »), which will be utilized for the future expansion of the service demand with generally modest additional investment costs.

f) The comparison among different systems should be based on the evaluation of a convenient figure of merit, to characterize any given plant, which should be a convenient function of the ratio between *cost* and the *utility* provided in the « study period » by the given plant. In fact an economic comparison among different plants may be performed on a costs basis only, in the case they meet the same service demand, provide service over the same period of time, and have the same service capability. Because all these requirements are not always met, it is also necessary an evaluation of the differencies and qualities of service (i.e. an evaluation of what will be later defined the « utility » forecast during the « study period »).

g) The figure of merit, which should characterize a given plant, should be defined in a way that it remains fairly constant as the length of the « study period » is changed. Only in this case this figure of merit can really characterize the given plant for all its life period, because it is then the forecast of the cost-utility ratio of the plant, over its entire life period, made during the « study period » (3).

In the above criteria it has been pointed out the importance of taking into account, in addition to the « costs », what we have called the « utility » provided by a system in a given plant, because it may be different for different systems.

The word *utility* has been given here a wider meaning than that of the *income*, expected during the operation of the plant and due to paying telephone traffic or other paying services. Its meaning has been brodened out to take into account that some of the available circuits may be used by the Administrations for various operational services also when they are not used for paying services (for example when part of the circuits are used as spare circuits, or when the plant is used for alternate routing in a communication network, etc).

3. - « Utility » of a transmission system.

A quantitative evaluation of the *utility* of a transmission system is not an easy problem, but it is really not needed for the purpose of the paper (i.e. the definition and evaluation of a convenient figure of merit to compare different systems). It is sufficient to observe that the « utility » $W(u)$, provided during a given year u by a plant, should be a quantity proportional to the overall number N_u of equivalent telephone circuits (TFc.) available in said year (i.e. installed up to the u-th year).

(3) Said figure of merit, according to previous criteria, cannot be a constant, but will be a function of the service demand expansion rate δ over the given route, of the initial service capability already available on the route through other existing facilities, of the appropriate compound interest rate τ, of the life forecast for the plant and its parts, of the investments timing, which has been planned out, etc. Because it is not convenient to install new parts of a plant too frequently, it will be reasonably to forecast investments for new equipment to meet expansion of service demand at periods no shorter than 4 to 5 years and investments for new transmission media at periods no shorter than about 10 years.

This figure or merit, therefore, will characterize a given plant only for a given transmission route and for a given service demand forecast and for a given plan of investments. To compare different systems it is therefore necessary to evaluate said figure of merit for the same transmission route and under the same assumptions of service demand expansion.

For a given transmission route, of length d_t, over which different plants shall be compared, it is convenient to assume in the following that the utility, which is clearly a quantity growing with the length d_t of the route, be a quantity proportional also to d_t:

$$W(u) = K_w N_u d_t . \tag{1}$$

It should be pointed out that the relationship between $W(u)$ and d_t for different routes is generally more complex than a linear one. However eq. (1) may be assumed over a given route, provided that the proportionality constant K_w is given the meaning of average annual utility per unit length (for example per km) of one telephone circuit over said route. In the following K_w will be called average unit annual utility of the given route.

Although K_w depends on the particular route under consideration, however its evaluation is not needed, because it is the same for all the systems, which should be compared.

Both K_w and $W(u)$ may be expressed in the same unit as that used for cost, because utility can always be converted into an equivalent income, that is into money. In this paper we will use, both for costs and utility, the arbitrary account unit U.

To compare different plants we need to evaluate the present value of the total utility W_{tu}, provided by a plant after a given number of years u, or the corresponding normalized value w_u:

$$w_u = \frac{W_{tu}}{W(u)} = \frac{W_{tu}}{K_w N_u d_t} = F(\delta, \tau, u, s) . \tag{2}$$

This quantity has therefore the meaning of the average present value of utility per TFc., per km and per unit of K_w.

Because the utility can be converted into an equivalent income and therefore into money the present value of utility (W_{tu} or w_u) can be evaluated following the same rules used to obtain the present value of the costs. This value is a function of the service demand expansion rate δ, of the appropriate compound interest rate τ, of the number u of years considered and of the number s of years expected for a complete utilization of the total service capability N_t of the system. Because s is also a function of δ and of the initial capability N_i of the route, available at the year $u = 0$ over other existing facilities, w_u may be expressed also as a function of δ, τ, u and N_i. N_i, N_u and N_t will be considered here for convenience as numbers of equivalent telephone circuits (TFc).

The function F depends on the expansion of the expected service demand. In this paper, for the sake of simplicity, we will assume an exponential expansion law; however it is easy to modify the results, when other laws of expansion are assumed. It follows therefore that the value of N_u increases with u according to eq. (3):

$$N_u = N_i[(1+\delta)^u - 1] , \tag{3}$$

up to year s-th of saturation of the overall plant capability N_t, which is given by eq. (4):

$$s = \frac{\log(1 + N_t/N_i)}{\log(1+\delta)} . \tag{4}$$

For the assumed law of expansion the function F is expressed by two different equations:

$$\begin{aligned} F_1 &= \frac{N_i}{N_t} f_1(u,s), \text{ (for } u > s); \\ F_2 &= \frac{N_i}{N_u} f_2(u,s) \text{ (for } u < s) . \end{aligned} \tag{5}$$

In eq.s (5), according to the two cases $u > s$ or $u < s$, f_1 and f_2 are the following functions, which for given δ and τ depend only on u and N_i (or s):

$$f_1(u,s) = \frac{\delta(1+\tau)}{\tau(\delta-\tau)} \left[\left(\frac{1+\delta}{1+\tau}\right)^s - 1\right] - \frac{(1+\delta)^s - 1}{\tau(1+\tau)^u} \text{, (for } u > s); \tag{5'}$$

$$f_2(u,s) = \frac{\delta(1+\tau)}{\tau(\delta-\tau)} \left[\left(\frac{1+\delta}{1+\tau}\right)^u - 1\right] - \frac{(1+\delta)^u - 1}{\tau(1+\tau)^u} \text{, (for } u < s) . \tag{5''}$$

If the plant life is equal to n years, eq. (2) with $u = n$ gives the normalized value w_n of the utility,

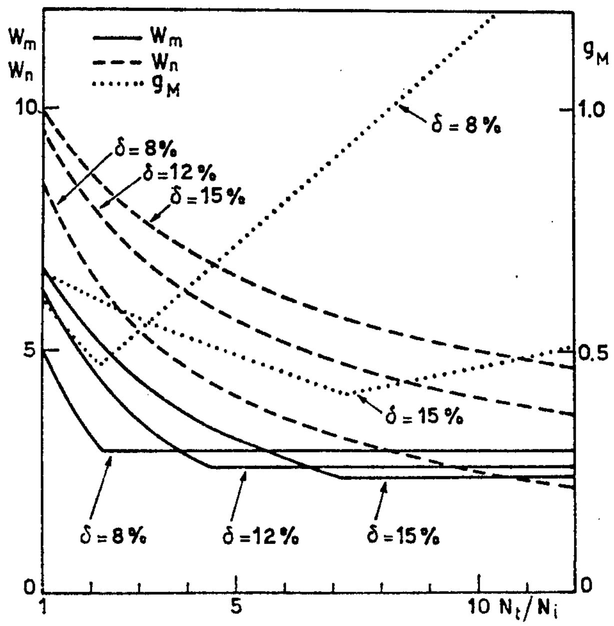


Fig. 1. - Behaviour of w_m, w_n, $g_M = w_m/w_n$, vs. N_t/N_i for different values of the rate δ of service demand expansion. The curves are calculated for $m = 15$, $n = 40$, $\tau = 8\%$.

provided along the total life of the considered plant; if the length of the study period is equal to m years, eq. (2) with $u = m$ gives the normalized value w_m of the utility, provided along the study period.

Fig. 1 shows the behaviour of w_m and w_n (for $m = 15$ and $n = 40$) as a function of N_t/N_i for $\tau = 8\%$ and for different values of δ.

The overall utility w_n (or $W_{t,n}$) is obviously a decreasing function of s and a growing function of n (but slower and slower for larger n).

4. - Available methods for the costs evaluation.

Before discussing possible methods of evaluation of a figure of merit of a plant, which takes into account both cost and utility, it may be useful to recall in this section the available methods of evaluation of costs and to compare them.

Economic comparisons are generally based on the three basic forms of cost studies of PVE, AC and PVAC. The three methods are mathematically equivalent [1] and their use is sufficient when the systems to be compared meet the same service demand, provide service over the same period of time, provide the same service capability (i.e. the same « utility »).

In such cases the choice among them depends on the timing of expenditures and retirements [1]. Generally the PVE (Present Value of Expenditures) study form (where all the investments are converted to the present year - or year $u = 0$ of the plant) is a convenient form for both coincident and non coincident investment costs, provided the retirements are coincident (4). It requires the forecast of the investment costs up to the end of the plant. Such evaluation can be extended to a very far date, provided it is possible to anticipate that the future expansion of the plant will be performed by using systems of the same type and the same technology (5) [2].

The study form AC (Annual Costs) converts the lump-sum first cost, with consideration given to net salvage, into an annual cost or annuity, sum of interest and of recovering of investment (amortization), with uniform distribution along the life and adds it to the operations annual cost which is generally constant. This study form seems to be convenient both for coincident and for non-coincident retirements, provided the investments are coincident (6) and the annual cost is constant during the life of the plant [1].

When both the investment costs and the retirements are non-coincident it is more convenient the study form PVAC (Present Value of Annual Costs) [1], which first converts any expenditure into annual costs and then converts all the annual costs in their present value. The PVAC may be evaluated only up to a limited length of time, the « study period » and therefore allows to compare different plants by avoiding forecasts extended too much in the future, according to criteria a and c of sect. 2.

In the case of a « study period » of m years, eq. (8) gives the PVAC, during this period of time, relevant to an investment cost C_u, carried out in the u-th year, requiring an operation annual cost εC_u with a salvage $r C_u$, at the end of its life of n years:

(4) For example the PVE of the expenditure C_u, made in the year u-th, is given by $C_u/(1+\tau)^u$.

(5) The overall PVE of a plant, with a life of n years which requires an investment C at the year 0, an annual operation cost εC and alloys a salvage $r C$ at the end of its life, in case of extension up to the year $u = \infty$, is as well known [2]:

$$\text{PVE} = C\left[1 + \frac{1-r}{(1+\tau)^n - 1} + \frac{\varepsilon}{\tau}\right] \tag{6}$$

(6) The AC of the expenditure C, of which we have already considered the corresponding PVE (5) is:

$$\text{AC} = C\tau\left[1 + \frac{1-r}{(1+\tau)^n - 1} + \frac{\varepsilon}{\tau}\right]. \tag{7}$$

$$(8)\qquad (\mathrm{PVAC})_u = C_u \left[1 + \frac{1-r}{(1+\tau)^n - 1} + \frac{\varepsilon}{\tau}\right] \cdot$$
$$\cdot\, [(1+\tau)^{-u} - (1+\tau)^{-m}]\,.$$

Eq. (8) shows that the PVAC is coincident obviously with the PVE given by eq. (6), when $u = 0$ and $m = \infty$, and is coincident with C_u when $r = 0$, $\varepsilon = 0$, $u = 0$, $m = n$.

The overall PVAC is evaluated by adding the PVAC's of all the expenditures made in the « study period ».

The PVAC study form is therefore more general than PVE and AC. It is a satisfactory form of study to compare different plants, when they have the same « utility » during their whole life and not only during the study period. Only in this case it meets the premises of sect. 2. However the result of this form of analysis leads always to a value which is a function of m (i.e. of the length of the study period) and cannot be assumed as a figure of merit. In cases where the systems under evaluation have not the same capacity, also the PVAC study form does not meet the basic premises *e*, *f* and *g*.

A tentative study form, which takes into account both the different cost and the different « utility » of different systems and meets all the premises of sect. 2, is discussed in the next section.

5. - Tentative definition of a figure of merit as a convenient ratio between cost and utility.

In the above sections it has been pointed out that a comparison among different systems based on the simple evaluation of costs does not seem to be satisfactory in the general case of different service capabilities.

When the service demand expansion and the investment costs can be forecast along the whole life of the plant, a reasonable comparison could be made on the basis of the ratio between the present value of all expenditures (PVE) and the present value of the overall utility W_{tn}, as defined in sect. 3. A possible extension of this criterion to the more general case, where we may consider to be acceptable forecasts those limited to a period of only m years (the « study period »), could be made on the basis of the ratio between the PVAC of all the expenditures made in said period and the corresponding present value of the utility provided in the same period. Nevertheless this definition does not seem satisfactory, because it leads to define a figure of merit which depends also on the length m of the « study period » and not only on the characteristics of the system and of the given transmission route.

It is easy to observe however that the variability of said ratio with the length m is due only to the fact that the annual utility distribution law along the « study period » is different from the corresponding distribution law of the annuities, which is used for the evaluation of the PVAC. Said ratio would be constant only if both distribution laws were the same. However the annuities, for the amortization of the investment costs of the plant equipment and for the corresponding operation costs, already have, in a first approximation, the same distribution law as the annual « utility » (in fact the equipment is installed following approximately the expansion of the service demand). The main discrepancy between the annuities distribution and the utility distribution lies only on the fact that the annuities, corresponding to the investment cost for the initial installation of the transmission medium and for its maintenance, according to the PVAC study form, follow an uniform distribution law along the plant life. The uniform distribution law, assumed by the PVAC method, may be justified since is the usual form of amortization of an investment. However, from a general logical point of view, it seems to be rather arbitrary, that other laws of distribution, which are mathematically equivalent to the uniform one, may not be taken into account, although they could lead to a more satisfactory study form (no matter if not usable as actual forms of amortization).

For example the annuities distribution law may be chosen to be mathematically equivalent to the uniform distribution law in a way that the ratio between the present value of annual costs and the present value of the annual utility during the « study period » is constant with the length of the « study period » [3].

This distribution law is clearly the same as that of the annual utility and therefore is the same as that of the number N_u of the available equivalent telephone circuits.

The present value of annual costs, evaluated according to such non-uniform distribution law and indicated here as PVWAC (Present Value of Weighted Annual Costs) corresponds to a mathematically equivalent amortization law, where the sum of the annual interest, recovery of investment and operation costs has an annual distribution law proportional to N_u. This kind of hypothetical amortization law is mathematically equivalent to an uniform distributed amortization law in the sense that PVWAC = PVAC, when the evaluation is extended to the whole life of the plant.

As pointed out in sect. 3 the use of the quantity W_{tm} is not convenient, because W_{tm} depends on the average unit annual utility K_w, which is of not easy evaluation. Due to the fact that K_w, on a given transmission route, is the same for all the transmission systems to be compared, it is possible to overcome this difficulty, by using a study form based on the figure of merit R defined [3] as the ratio between the $(\mathrm{PVWAC})_m$ and W_{tm}/K_w, evaluated in the « study period », which is no longer a function of K_w. This ratio R may also be defined as the ratio between the unit value $\mathcal{C}_w$ of the PVWAC, i.e. the average value per km and per TFc of the PVWAC in the « study period », and the unit value w_m of the utility in the same period. In fact $\mathcal{C}_w$ is:

$$(9) \qquad \mathcal{C}_w = \frac{(\mathrm{PVWAC})_m}{N_m\, d_t}$$

and then R is given by

$$(10) \qquad R = \frac{(\mathrm{PVWAC})_m}{\dfrac{W_{tm}}{K_w}} = \frac{\mathcal{C}_w}{w_m} \, .$$

R is therefore expressed in the same cost unit used for $\mathcal{C}_w$ and has the meaning of the minimum value of K_w on the considered transmission route, for which the utility of the plant is greater than the correspondent cost. The ratio R/K_w gives the actual ratio between $(\mathrm{PVWAC})_m/W_{tm}$, i.e. between cost and utility, when the annuities arde distributed along the life of the plant in the same way as the utility.

Because R does not depend on m, it may be considered as the more probable value along the whole life of the plant (i.e. when costs and technologies remain the same along the whole life) and therefore takes automatically into account the different service capability expansion that different systems may provide after the « study period » along their life period.

It may be convenient to evaluate the unit cost $\mathcal{C}_w$, as a function of unit costs $\mathcal{C}_M$, $\mathcal{C}_A$ and $\mathcal{C}_T$ (referred to the transmission medium, the repeater equipment and the terminal station equipment respectively), conventionally defined for the plant equipped for its maximum capacity [7] at the year $u = 0$, and therefore defined in a non-ambiguous way.

The cost $\mathcal{C}_w$ can be written as the following weighted sum:

$$(12) \qquad \mathcal{C}_w = g_M\ \mathcal{C}_M + g_A\ \mathcal{C}_A + g_T\ \mathcal{C}_T \, .$$

In eq. (12) the weights g_M, g_A and g_T are convenient functions of δ, τ, N_i, N_t, m and of the forecast life both of the plant (n) and of the equipment (n_a) and take also into account the corresponding salvage (r_M, r_A and r_T) and the operation annual costs (ε_M, ε_A and ε_T) in percent values of the corresponding plant costs.

The functions g_M, g_A and g_T are easily obtained. For example, if the salvage is $r_M = 0$, g_M is given by:

$$(13) \qquad g_M = \left\{ 1 + \frac{\varepsilon_M}{\tau} \left[1 - (1+\tau)^{-n}\right] \right\} \frac{f(m,s)}{f(n,s)} \, \frac{N_t}{N_m} \, ,$$

where $N_m = N_t$, if $s < m$. In eq. (13) $\varepsilon_M\ \mathcal{C}_M$ is the unit annual operation and maintenance cost for the transmission medium and for the general facilities, $f(n,s)$ is given by eq. (5′) (because it must be $s < n$) and $f(m,s)$ is given by eq. (5′), when $s < m$, or by eq. (5″) when $s > m$.

Fig. 1 shows the behaviour of g_M (for $\varepsilon_M = 0$ and $r = 0$) versus N_t/N_i for different values of δ, when $m = 15$, $n = 40$, $\tau = 8\%$. It can be shown that the curves do not change appreciably by varying τ or n.

The ratio g_M/w_m is not a function *of* m also in the general case, where a different value of τ is convenient to evaluate cost and utility. When the same value of τ is used, the ratio $[N_t f(m,s)]/[N_m f(n,s)]$ is equal to w_m/w_n and the ratio g_M/w_m is equal to $1/w_n$.

The functions g_A and g_T are generally equal, because the installation of new terminal equipment follows the same expansion law as the repeater equipment. However g_A and g_T do not coincide with g_M, because they depend on the planned investment timing; this may not bring about the minimum value of g_A/w_m and therefore of R to allow elapsing a convenient period of time between the installation of new equipment, and to take into account a possible unforeseen service demand expansion. For these reasons the ratio g_A/w_m may exhibit small changes by varying m, which may be tolerated. Also in the evaluation of g_A, it is convenient to use suitable weights of the annualities for any investment in order to reduce the variation of g_A/w_m with m.

[7] If C_M is the cost per km of the transmission medium, N_t the system overall capacity in TFc., C_A the cost of a two-way repeater equipment of N channels capacity, d the repeater stations distance, C_T the cost of a two-way additional equipment available in a terminal station and associated to any N TFc, d_T the distance between terminal stations, $\mathcal{C}_M$, $\mathcal{C}_A$ and $\mathcal{C}_T$ are given by:

$$(11) \qquad \mathcal{C}_M = \frac{C_M}{N_t} \, , \quad \mathcal{C}_A = \frac{C_A}{N\, d} \, , \quad \mathcal{C}_T = \frac{C_T}{N\, d_t} \, .$$

If p is the number of two-way RF channels or coaxial tubes, used as spares or other services since the first year, and $q_0, q_1, q_2 \ldots$ are the number of two-way RF channels or coaxial tubes installed at dates $u_0 = 0, u_1, u_2 \ldots$ (years), g_A may be evaluated by the following relationship (assuming the salvage $r_A = 0$, $m \leqslant n_a$ and the annual operation cost per repeater $\varepsilon_A \, \mathcal{C}_A$ proportional to $\mathcal{C}_A$):

$$
\begin{aligned}
g_A = {} & \frac{N}{N_m}\left[1+\frac{\varepsilon_A}{\tau}\left(1-\frac{1}{(1+\tau)^{n_a}}\right)\right] \cdot \\
& \cdot \left[p\,\frac{f(m,s)}{f(n_a,s)} + q_0\,\frac{f(m,u_1)}{f(n_a,u_1)} + \right. \\
& + \frac{q_1}{(1+\tau)^{u_1}}\,\frac{f(m-u_1,u_2-u_1)}{f(n_a,u_2-u_1)} + \\
& \left. + \frac{q_2}{(1+\tau)^{u_2}}\,\frac{f(m-u_2,u_3-u_2)}{f(n_a,u_3-u_2)} + \ldots \right].
\end{aligned} \tag{14}
$$

In eq. (14) the functions f are given by eq. (5) or eq. (5') by replacing u with n_a or m or $m-u_i$ and s with $u_{i+1}-u_i$ or again s [8].

In the following section few examples are given of application of the study form using the ratio R in some very idealized cases and the method is compared with the PVAC study form. Also in the PVAC method we will refer to an unit cost $\mathcal{C}$ = PVAC/ $/N_m d_t$ (cost per km and per TFc). In addition we will compare the R ratio with the ratio between $\mathcal{C}$ and w_m, i.e. between PVAC and utility.

The evaluation of $\mathcal{C}$ has been made with the same eq. (12) when in the eq. (13) we replace (in case of salvage $r = 0$) $f(m,s)$ and $f(n,s)$ with the new functions:

$$
f(m) = 1-(1+\tau)^{-m}, \quad f(n) = 1-(1+\tau)^{-n}, \tag{15}
$$

and in the eq. (14) we introduce the new functions (15) (with n_a instead of n in $f(n)$ and m, or $m-u_1$, or $m-n_2 \ldots$ instead of m in $f(m)$).

In the evaluation of R, as pointed out above, the functions g_M and g_A do not coincide. However in a first approximation it is possible to assume $g_A = g_M$ and, in case the same value of τ is assumed in the evaluation of both utility and cost, it is possible to use the following simple equation:

$$
R \cong \frac{\mathcal{C}_M + \mathcal{C}_A + \mathcal{C}_T}{w_n}. \tag{16}
$$

6. - Examples of applications of the study form using R and comparison with the PVAC study form.

The ratio R, defined in sect. 5, may be used to compare two different systems or to optimize one system, by finding the best choice of its characteristics (distance between repeater stations, overall available bandwidth, channelling, repeater capacity, kind of modulation, etc.) which results in a minimum of R. In the following example the use of the R method is compared with that of PVAC method to evaluate different systems.

In the idealized examples, here given for the sake of simplicity, we will consider only the contribution of $\mathcal{C}_M$ and $\mathcal{C}_A$ to R or $\mathcal{C}$ and we will assume $r_M = r_A = 0$ and $\varepsilon_M = \varepsilon_A = 0$. The costs are given in arbitrary cost units U.

In all the example it has been assumed $n = 40$, $n_a = 15$, $m = 15$, $\tau = 8\%$ (both for costs and utility); a fixed period of 5 years has been assumed between new equipment installations.

6.1. - *Example n. 1: Comparison between two circular waveguide systems.*

We want to compare two circular waveguide systems to be installed along a transmission route. The initial service capability over other facilities is $N_i = 40\,000$ TFc.

The main characteristics of the two different circular waveguide systems, are summarized in the caption of fig. 2. The first system (subscript 1) has a smaller service capability and a smaller cost of the installed waveguide .The second system (subscript 2) besides a higher service capability ($N_{t2} > N_{t1}$) has a smaller waveguide loss and therefore the distance between repeaters is higher ($d_2 > d_1$), which results in a lower unitary cost of the repeaters ($\mathcal{C}_{A2} < \mathcal{C}_{A1}$), because the same cost C_A and the same capacity N per repeater have been assumed. The higher service capability and the lower loss are attained with an expected higher cost of the installed waveguide ($C_{M2} > C_{M1}$). Fig. 2 shows the maximum value allowed to C_{M2}/C_{M1} in order that the higher capacity system be more convenient, according to the R method (curve a) or to the PVAC method (curve b). The curve d has the same meaning of

[8] When the « study period » m is longer than the equipment life n_a, it should be added also the cost of the replacement of the obsolete equipment. In this case an uniform distribution law should be used and the appropriate functions f to be used are given by the following eq.s (15).

curve a, but it is evaluated by assuming that the cost of the repeaters equipment is so low in both systems (due for example to advances in technology) to be negligible in comparison to the waveguide cost. The curve d shows therefore, if compared with curve a, the influence of the equipment cost in the given example.

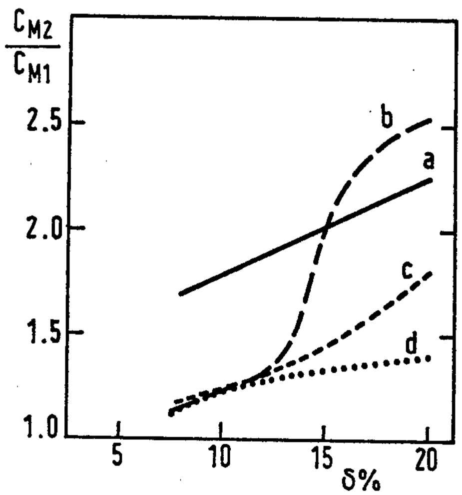


Fig. 2. - Behaviour of C_{M2}/C_{M1} vs. δ, where C_{M2}/C_{M1} is the maximum value of the ratio between the costs of two installed circular waveguides, for which the system of larger capacity is more convenient. Curve a has been evaluated according to the R method; curve b according to the PVAC method; curve c according to the $\mathcal{C}/w_m$ method; curve d has the same meaning as that of curve a, but it is evaluated by assuming the cost of the equipment of the repeater stations to be negligible. The two systems have the following main characteristics:

$N_1 = N_2 = 7\,680$ TFc; $N_{t1} = 200\,000$ TFc;

$N_{t2} = 320\,000$ TFc; $C_{A1} = C_{A2} = 60 \cdot 10^3\ U$;

$C_{M1} = 70 \cdot 10^3\ U$/km; $d_1 = 20$ km; $d_2 = 40$ km.

It has been assumed $N_i = 40\,000$ TFc; $p = 2$, $m = 15$, $n = 40$, $n_a = 15$, $\tau = 8\%$.

The comparison between curves a and b shows that the two methods give the same result only for $\delta \cong 15\%$, but quite different results for other values of δ. For example for a considerable higher cost of the transmission medium (for example $C_{M2} = 1{,}5\, C_{M1}$) the larger capacity waveguide, according to the R method, is always more convenient, while, on the contrary, the PVAC method for $\delta < 14\%$ indicates more convenient the lower capacity system. In addition the PVAC method seems to be too much favourable for the higher capacity system, in case of higher values of δ. However for $\delta > 13\%$ use of PVAC method gives results of doubtfull meaning. This is more clear from fig. 3, which gives the behaviour of $\mathcal{C}_1$ and $\mathcal{C}_2$, R_1 and R_2 for $C_{M2} = 1{,}5\, C_{M1}$. In this case $\mathcal{C}_1$ presents a minimum for $\delta \cong 13\%$, i.e. when s is equal to m for the system n. 1. When δ increases to higher values than 13% the PVAC in the « study period » increases, because the expenditures for the equipment must be planned at earlier dates and the service capability of the system N_m has reached its maximum value N_t before the end of the « study period ». As a consequence also $\mathcal{C}_1$ must increase. However it must be pointed out again that for $\delta > 13\%$ the service capability of the two systems at the end of the « study period » is different and the PVAC method has lost any meaning.

Curve c in fig. 2 and curves $\mathcal{C}_1/w_m$ and $\mathcal{C}_2/w_m$ in fig. 3 show the results of calculation, if we use as comparison study form the ratio between the PVAC, and the utility, that is the ratio $\mathcal{C}/w_m$. The comparison by means of this last ratio seems more satisfactory than that using $\mathcal{C}_1$ and $\mathcal{C}_2$, but the result are still rather different than those given by

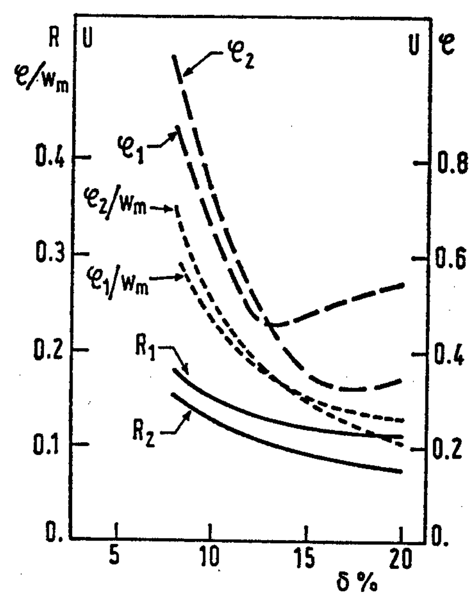


Fig. 3. - Behaviour of R_1 and R_2, $\mathcal{C}_1$ and $\mathcal{C}_2$, $\mathcal{C}_1/w_m$ and $\mathcal{C}_2/w_m$ vs. δ, for the same circular waveguide systems of fig. 2, when $C_{MC} = 105 \cdot 10^3\ U$/km.

the R method. For example for the $\mathcal{C}/w_m$ method, if $C_{M2} = 1{,}5\, C_{M1}$, the larger capacity waveguide is less convenient for $\delta < \sim 16\%$, while on the contrary it results to be always more convenient according to the R method.

The R value, in addition, exhibits the significant property to be practically constant by varying m, while both the values of $\mathcal{C}$ and of $\mathcal{C}/w_m$ depend on the length of the « study period », as shown in the example of fig. 4, where the behaviour of R_1 and

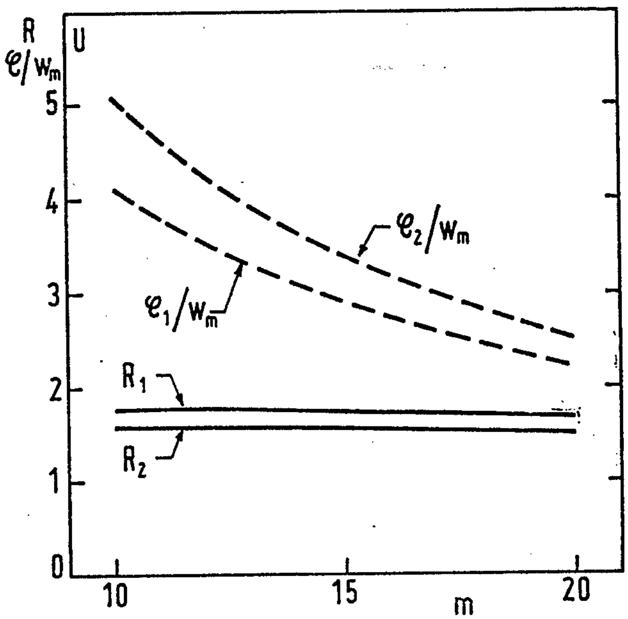


Fig. 4. - Comparison of the behaviour of $R = \mathcal{C}_w/w_m$ and $\mathcal{C}/w_m$ vs. m. Curves refer to the same system of fig. 3, for $\delta = 8\%$.

R_2, $\mathcal{C}_1/w_m$ and $\mathcal{C}_2/w_m$, versus the « study period » length m, for the same waveguide systems of fig. 3, when $\delta = 8\%$, is shown.

The behaviour of $\mathcal{C}_1/w_m$ and $\mathcal{C}_2/w_m$ on the contrary is substantially dependent on the length of the « study period ». Clearly if the study period length could be increased up to the end of the plant life, the values of $\mathcal{C}_1/w_m$ and $\mathcal{C}_2/w_m$ approach the limit values R_1 and R_2 respectively.

In the example of fig. 4 the second system results to be the more convenient one, according to the R method, while an opposite result is obtained according to the $\mathcal{C}/w_m$ method.

6.2. - *Example n. 2: Comparison between a circular waveguide system and a coaxial cable carrier system.*

In this example a comparison is made between a circular waveguide system and a coaxial system to be installed on the same transmission route (as that of example n. 1). The main characteristics of the two systems are summarized in the caption of fig. 4 (subscript 1 for the coaxial cable system and subscript 2 for the waveguide system).

The coaxial cable is a multitube cable (16 tubes) with 10 800 TF channels per tube.

Fig. 5 shows the maximum allowed value of C_{M2}/C_{M1} in order that the waveguide system becomes more convenient, according to the R method (curve a) or to the PVAC method (curve b), in case of $N_i = 40\,000$ TFc. Curve a' and b' have the same meaning, but are evaluated in case of $N_i = 32\,000$ TFc. Curves c and c' have the same meaning as curves a and a' respectively, but are evaluated assuming

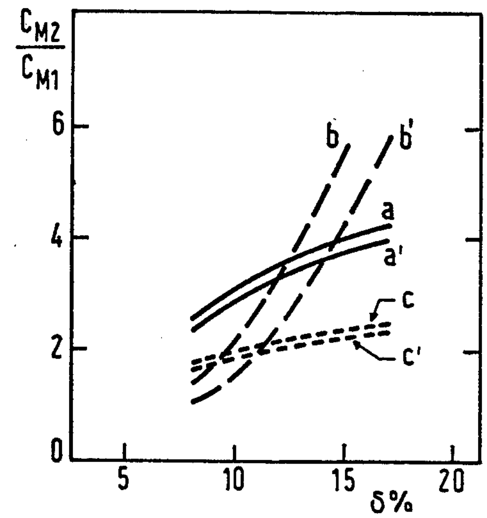


Fig. 5. - Behaviour of C_{M2}/C_{M1} vs. δ, where C_{M2}/C_{M1} is the maximum value of the ratio between the costs of the installed transmission media of a circular waveguide system (subscript 2) and a multitube coaxial carrier cable (subscript 1) for which the waveguide system is more convenient. Curves a (for $N_i = 40\,000$ TFc) and a' (for $N_i = 32\,000$ TFc) have been evaluated according to the R method; curves b (for $N_i = 40\,000$ TFc) and b' (for $N_i = 32\,000$ TFc) have been evaluated according to the PVAC method; curves c and c' have the same meaning as that of curves a and a' respectively, but have been evaluated by assuming the cost of the equipment of the repeater stations to be negligible. The two systems have the following main characteristics $N_1 = 10\,800$ TFc; $N_2 = 7\,680$ TFc; $N_{t1} = 86\,400$ TFc: $N_{t2} = 320\,000$ TFc; $C_{M1} = 85 \cdot 10^3\ U$; $d_1 = 1{,}5$ km; $d_2 = 40$ km; $C_{A1} = 12 \cdot 10^3\ U$. It has been assumed $p_1 = 0$, $p_2 = 2$, $m = 15$, $n = 40$, $n_a = 15$, $\tau = 8\%$.

the equipment cost to be negligible, if compared to that of transmission media.

Fig. 6 shows the corresponding behaviour of $\mathcal{C}_1$ and $\mathcal{C}_2$, R_1 and R_2, $\mathcal{C}_1/w_m$ and $\mathcal{C}_2/w_m$, for $C_{M2} = 1{,}5\ C_{M1}$ and $N_i = 32\,000$ TFc.

In this example the service capability of the coaxial cable carrier system would be saturated in only 8 years for $\delta \cong 15\%$, when $N_i = 40\,000$ TFc, and for $\delta \cong 18\%$, when $N_i = 32\,000$ TFc. The corresponding curves have been therefore plotted only for lower values of δ. However also in this example the PVAC method gives results of doubtful meaning, when $s < m$ (i.e. when $\delta > \sim 8\%$ for $N_i = 40\,000$ TFc. or $\delta > \sim 9\%$ for $N_i = 32\,000$ TFc).

In fig. 7. curves R'_1 and R'_2 have the same meaning as that of curves R_1 and R_2, but have been evaluated with the approximate eq. (16) to give an idea of the discrepancies which may be expected by using eq. (16).

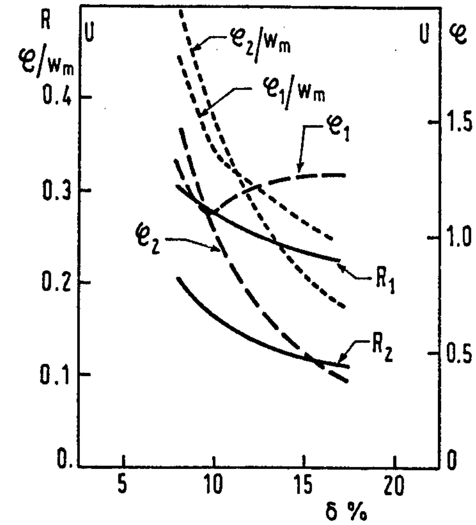


Fig. 6. - Behaviour of R_1 and R_2, ϱ_1 and ϱ_2, ϱ_1/w_m and ϱ_2/w_m vs. δ, for the two systems - coaxial cable carrier system (subscript 1) and waveguide system (subscript 2) - already considered in fig. 4, when $C_{M2} = 130 \cdot 10^3$ U/km and $N_i = 32\,000$ TFc.

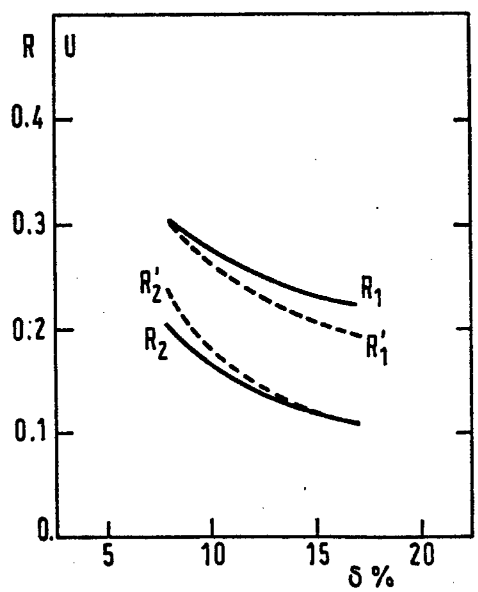


Fig. 7. - Comparison of the curves R_1 and R_2, evaluated for the same systems of fig. 6, with the approximate curves R_1' and R_2', evaluated with eq. (16).

6.3. - *Example n. 3: Comparison between two coaxial cable carrier systems of different capacity.*

In this example the R and PVAC methods are compared to find out the minimum initial service demand N_i (over existing facilities), above which a larger capacity multitube coaxial carrier system becomes more convenient than a lower capacity system. The two systems to be compared use a 8-tube and a 16-tube coaxial cable respectively and the same number $N = 10\,800$ telephone channels per tube.

The main characteristics of the two systems are summarized in the caption of fig. 8 (subscript 1 for the 8-tube system and subscript 2 for the 16-tube system).

Fig. 8 gives the maximum allowed value of the ratio C_{M2}/C_{M1}, in order that the 16 tube system becomes more convenient; this ratio is plotted versus N_i/N for different values of δ. Curves a are evaluated according to the R method and curves b according to the PVAC method (a_1 and b_1 for $\delta = 8\%$, a_2 and b_2 for $\delta = 10\%$, a_3 and b_3 for $\delta = 15\%$).

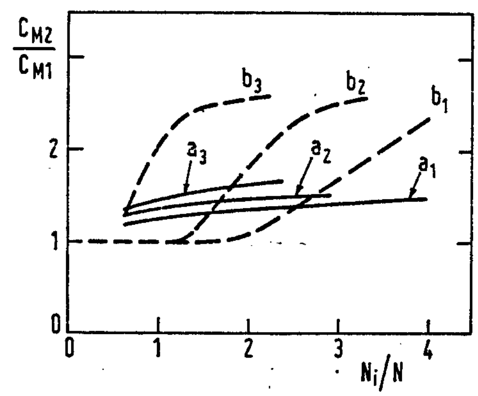


Fig. 8. - Behaviour of C_{M2}/C_{M1} vs. N_i/N, where C_{M2}/C_{M1} is the maximum value of the ratio between the initial investment costs of the transmission media relevant to two coaxial carrier systems (8-tube cable, subscript 1, and 16-tube cable subscript 2) for which the 16-tube system is more convenient; N_i is the initial service capability through other facilities on the given transmission route and $N = N_1 = N_2 = 10\,800$ TFc. is the number of telephone channels per tube of both systems. Other characteristics of both systems are: $N_{t1} = 43\,200$ TFc., $N_{t2} = 86\,400$ TFc., $C_{M1} = 50 \cdot 10^3$ U/km, $C_{A1} = C_{A2} = 12 \cdot 10^3$ U, $d_1 = d_2 = 1{,}5$ km. It has been assumed $p_1 = p_2 = 0$, $m = 15$, $n = 40$, $n_a = 15$, $\tau = 8\%$. Curves a have been evaluated according to the R method; curves b according to the PVAC method (a_1 and b_1 for $\delta = 8\%$; a_2 and b_2 for $\delta = 10\%$, a_3 and b_3 for $\delta = 15\%$).

The curves are plotted until $s \geqslant 8$ years for the 8-tube system. For larger values of N_i the 16-tube system may be more convenient (independently on economic convenience) to avoid a too short period of time between successive plant installations.

By varying the initial service capacity N_i or the rate of expansion δ the range of the maximum C_{M2}/C_{M1} values, needed in order that the 16-tube system becomes more convenient, results much narrower for the R-method than for the PVAC method.

7. - Conclusions.

In the previous sections we have introduced and discussed a convenient study method to perform an economic comparison between transmission systems, when they provide a different service capability or have a different service duration, when it is difficult to extend costs and service demand forecasts very far in the future and when it is necessary to confine the study to a limited period of time. The disadvantages of the PVAC study form have been analyzed and different approaches based either on the ratio between PVAC and utility or on the ratio between PVWAC and utility have been discussed and compared. Remarkable differences of results among the various study forms have been pointed out. The R method seems to be more attractive, because:

- it leads to a cost/utility ratio practically independent on the length of the « study period »;
- it allows to take into account both different service capability at the end of the study period and different service demand expansion capability after the study period;
- it gives the best forecast of the cost/utility ratio for the whole life of the plant.

The paper was first received on December 21, 1976.

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CSO: 5500

CALCULATION OF TRANSMISSION PARAMETERS, DESIGN OF COAXIAL STRUCTURES BY COMPUTER

Milan ALTA FREQUENZA in English No 9, Sep 77 pp 213-223

/Article by G. Corti, G. Tizzi/

/Text/

A method for calculating transmission parameters and designing coaxial structures by computer is described.

The paper deals with various types of coaxial structures for telecommunication purposes and with coaxial structures designed for power transmission which may also be employed for telecommunication transmission.

Measurements confirm the validity of the method.

There is a lot of literature on calculation of transmission parameters of coaxial structures.

In the references are shown the more significant papers examinated.

As can be seen, each of them deals with a special type of coaxial pair and usually in a limited range of frequency.

The purpose of this paper is to extend the study to all the more used coaxial structures and to the whole frequency range of any interest in telecommunication field.

The calculation of transmission parameters concerns coaxial pairs standardized by C.C.I.T.T., submarine cables, microwave cables, radio frequency cables and power cables.

Coaxial pairs with solid inner conductor and tubular outer conductor have been studied first and

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then the formulae obtained have been modified for application to other coaxial structures such as those having inner and outer tubular conductors and those with stranded conductors or braided outer conductor.

Configurations using the modified formulae are met in practice with telecommunication signal transmission on very large coaxial cables, on flexible coaxial cables for radio frequency and cables for power transmission. The formulae adopted are the results of both theoretical considerations and measurements.

This paper analyses in detail especially coaxial pairs type 2.6/9.5 mm, 1.2/4.4 mm and 0.7/2.9 mm.

Computer programmes have been written to calculate primary and secondary parameters, group and phase velocity.

The calculation of transmission parameters is based on dimensional data of cables manufactured by Industrie Pirelli S.p.A. Results of measurements are shown in addition to the calculated values in order to make a comparison.

A special method for design of coaxial pairs is also proposed; the values of characteristic impedance and of attenuation at a given frequency with relevant tolerances are generally set as input data.

A certain range of variation for dielectric constant ε_r is also considered. The dimensions of coaxial pairs for the imposed tolerances together with associated attenuation and impedance values are printed out.

Among the various solutions, the designer chooses the one which, according to his experience, best suits to the imposed conditions which may be both technical and economical.

I. - Calculation of transmission parameters.

I.1. - *Coaxial pair with solid inner conductor and tubular outer conductor.*

The formulae used for the calculation take into account the geometric and electrical characteristics of the coaxial pair, but do not consider the effect of the screen over the outer conductor generally obtained with steel tapes.

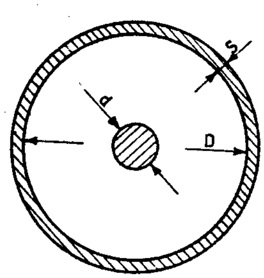

Fig. 1. - Cross section of coaxial pair with solid inner conductor and tubular outer conductor.

The hypothesis of neglecting the screen is acceptable over the whole frequency range generally considered.

Assuming an outer conductor sufficiently thin ($S/D < 0.2$), the results obtained with the above hypothesis have shown in fact a good approximation to the measured values both for high frequencies where these cables are generally used ($f \geqslant 60$ kHz) and at lower frequencies.

The tables and diagrams attached show some results of calculated and measured values.

For the coaxial pair 2.6/9.5 mm the calculations have been extended from 50 Hz to 500 MHz.

In particular, for rather high frequencies, if the geometric dimensions and the electric characteristics (resistivity, dielectric constant, magnetic permeability, dielectric loss angle) of the coaxial pair are exactly known, it can be considered on the basis of comparisons made with measured values, that the effective values of secondary parameters can be calculated with an error less than a few thousandths.

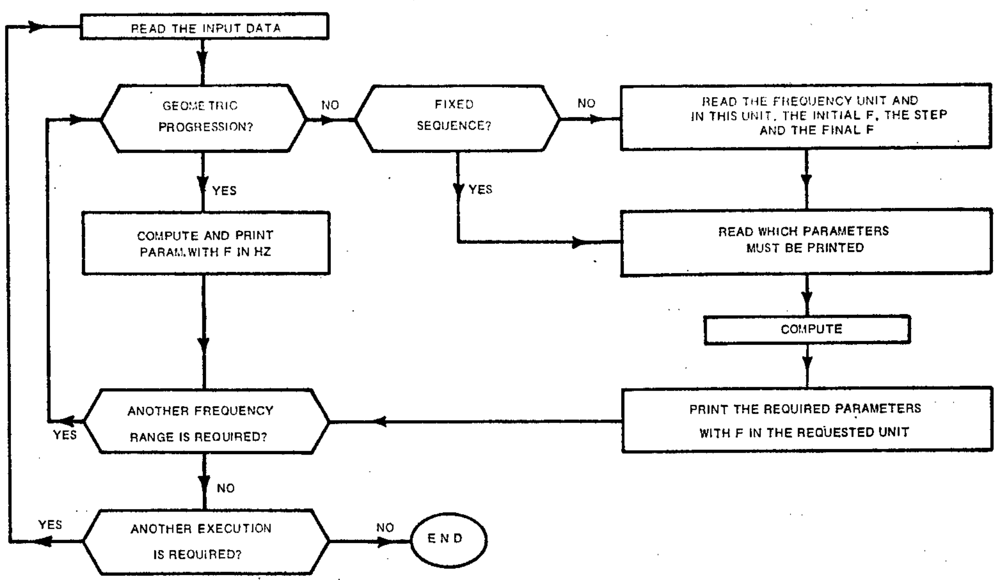

Fig. 2. - Flow chart for calculation of transmission parameters.

Due to the strading of coaxial pairs, it is necessary to take into account the fact that coaxial pair length is greater than cable length. For instance, in a 8 coaxial pair cable 2.6/9.5 mm manufactured by Pirelli this increase is about 0.5%.

The computer programme gives the possibility of choosing three different frequency sequencies (see fig. 2):

— arithmetic progression;

— geometric progression;

— fixed sequence.

The formulae employed are deduced from the general theory of transmission on circuits with uniformely distributed constants and therefore they have no frequency limit [1, 2].

The symbols used in the formulae are:

d = inner conductor diameter (mm);

D = inner diameter of the outer conductor (mm);

S = thickness of the outer conductor (mm);

ρ_i = resistivity of the inner conductor for the desired temperature $\left(\frac{\Omega\,\text{mm}^2}{\text{km}}\right)$;

ρ_e = resistivity of the outer conductor for the desired temperature $\left(\frac{\Omega\,\text{mm}^2}{\text{km}}\right)$;

μ_{ri} = relative magnetic permeability of the inner conductor;

μ_{re} = relative magnetic permeability of the outer conductor;

ε_r = average relative dielectric constant of the insulation between inner and outer conductor;

f = frequency (kHz);

$\tan\delta$ = tangent of loss angle of dielectric.

The computer programme is based on the following relationships:

$$(1) \qquad q = \pi \cdot d \cdot \sqrt{\frac{0.2 \cdot \mu_{ri} \cdot f}{\rho_i}}$$

reference parameter for calculation of skin effect in the inner conductor

(2) $$R_{0i} = \frac{4 \cdot \rho_i}{\pi \cdot d^2}$$

inner conductor d.c. resistance (Ω/km)

(3) $$k_i = \frac{q}{2} \cdot \frac{(ber\,q) \cdot (bei\,'q) - (bei\,q) \cdot (ber\,'q)}{(ber\,'q)^2 + (bei\,'q)^2}$$

skin effect coefficient for the inner conductor
where:

$ber\;q = \mathrm{Re}\,J_0(q \cdot \sqrt{j})$
J_0 = Bessel function of the order zero

$bei\;q = -\mathrm{Im}\,J_0(q \cdot \sqrt{j})$

$ber'q = -\mathrm{Re}\,\sqrt{j} \cdot J_1(q\,\sqrt{j})$
J_1 = Bessel function of the order one

$bei'q = \mathrm{Im}\,\sqrt{j} \cdot J_1(q \cdot \sqrt{j})$

(4) $$R_i = R_{0i} \cdot k_i$$

effective resistance of inner conductor (Ω/km)

(5) $$\delta_e = \frac{1}{\pi} \cdot \sqrt{\frac{\rho_e}{0.4 \cdot \mu_{re} \cdot f}}$$

depth of penetration for outer conductor (mm)

(6) $$k_e = \frac{S}{\delta_e} \cdot \frac{\mathrm{Sh}\,\frac{2S}{\delta_e} + \sin\frac{2S}{\delta_e}}{\mathrm{Ch}\,\frac{2S}{\delta_e} - \cos\frac{2S}{\delta_e}}$$

skin effect coefficient for outer conductor

(7) $$R_e = \frac{\rho_e \cdot k_e}{\pi \cdot S \cdot (D + S/k_e)}$$

effective resistance of outer conductor (Ω/km)

(8) $$R = R_i + R_e$$

where:

s = thickness of the inner conductor

(29) $$R_i = \frac{\rho_i \cdot k_i}{\pi s \left(d - \frac{s}{k_i}\right)}$$

effective resistance of. the inner conductor (Ω/km)

$$L_i = 2 \cdot 10^{-4} \frac{\delta_i \mu_{ri}}{d} \frac{\mathrm{Sh} \dfrac{2s}{\delta_i} - \sin \dfrac{2s}{\delta_i}}{\mathrm{Ch} \dfrac{2s}{\delta_i} - \cos \dfrac{2s}{\delta_i}} \tag{30}$$

inductance of inner conductor (H/km)

The calculation of the other parameters is as described in section I.1.

This configuration can be also generally employed for submarine coaxial cables.

For more precise calculations at low frequencies, the following exact expressions of R_i and L_i should be used [7]:

$$R_i = \mathrm{Re} \frac{2j\omega}{p_2} \cdot \frac{N_1(p_1) J_0(p_2) - N_0(p_2) J_1(p_1)}{N_1(p_2) J_1(p_1) - N_1(p_1) J_1(p_2)} \tag{31}$$

$$L_i = \mathrm{Im} \frac{2}{p_2} \cdot \frac{N_1(p_1) J_0(p_2) - N_0(p_2) J_1(p_1)}{N_1(p_2) J_1(p_1) - N_1(p_1) J_1(p_2)} \tag{32}$$

where:

$$p_1 = \left(\frac{d}{2} - s\right) \cdot \sqrt{- \frac{4\pi\omega\mu_i}{\rho_i} \cdot j}$$

$$p_2 = \frac{d}{2} \cdot \sqrt{- \frac{4\pi\omega\mu_i}{\rho_i} \cdot j}$$

$J_0(p)$ and $J_1(p)$ are the Bessel functions of order zero and one

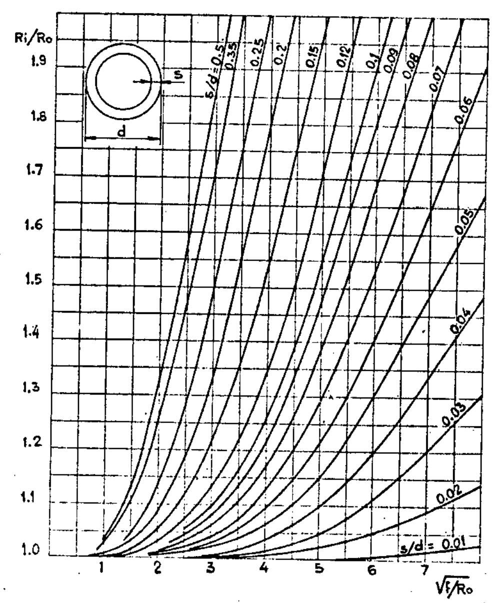

Fig. 4. - Skin effect in isolated tubes and wires [3].

f = frequency (kHz)

R_0 = conductor d.c. resistance (Ω/km)

R_i = effective resistance (Ω/km)

$N_0(p)$ and $N_1(p)$ are the Neumann functions of order zero and one.

However the calculation of R_i and L_i is quite complicated with (31) and (32), so that at least for the calculation of effective resistance R_i the diagram of fig. 4 can be employed.

I.3. - *Coaxial pair with stranded conductors.*

The calculation of transmission parameters of stranded structures is carried out using the same formulae employed for the equivalent solid structure introdu-

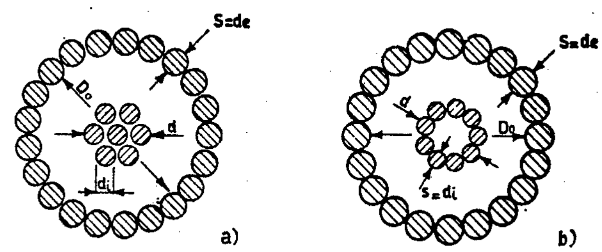

Fig. 5. - Cross section of coaxial pairs with stranded conductors.

cing a coefficient taking into account the increase of resistance due to the spiral path of the current.

The following types are considered:

a) coaxial pair with a central stranded conductor and outer tubular stranded conductor (fig. 5*a*);

b) coaxial pair with concentric tubular stranded conductors (fig. 5 *b*).

Symbols appearing in the formulae are the following:

d = diameter of the inner conductor (outer diameter if formed by a stranded tube);

d_i = diameter of wires forming the inner conductor (mm);

n = number of wires of the inner conductor;

Δ = additional thickness due to strand shaping of outer cond. (mm);

D_0 = inner diameter of the outer conductor (mm);

d_e = diameter of the wires forming the outer conductor (mm);

N = number of wires of the outer conductor;

s = thickness of the inner conductor (mm);

S = thickness of the outer conductor (mm);

μ_{ri} = relative magnetic permeability of the inner conductor;

μ_{re} = relative magnetic permeability of the outer conductor;

ρ_i = resistivity of the inner conductor for the desired temperature (Ω mm^2/km);

ρ_e = resistivity of the outer conductor for the desired temperature (Ω mm^2/km);

ε_r = average relative dielectric constant of the insulation between inner and outer conductor;
C_i = stranding loss of the inner conductor;
C_e = stranding loss of the outer conductor;
f = frequency (kHz).

For cables of type *a*, it is possible to employ the formulae of section I.1 with some modifications.

loop resistance of coaxial pair (Ω/km)

(9)
$$L_0 = 2 \cdot 10^{-4} \ln \frac{D}{d}$$

inductance of space between conductors (H/km)

(10)
$$L_i = \frac{R_{0i} \cdot q}{2\omega} \cdot \frac{(ber\, q) \cdot (ber'q) + (bei\, q) \cdot (bei'q)}{(ber'q)^2 + (bei'q)^2}$$

effective inductance of inner conductor (H/km)

(11)
$$L_e = 2 \cdot 10^{-4} \cdot \frac{\delta_e}{D} \cdot \frac{\mathrm{Sh}\,\frac{2S}{\delta_e} - \sin\frac{2S}{\delta_e}}{\mathrm{Ch}\,\frac{2S}{\delta_e} - \cos\frac{2S}{\delta_e}} \cdot \mu_{re}$$

effective inductance of outer conductor (H/km)

(12)
$$L = L_0 + L_i + L_e$$

total loop inductance (H/km)

(13)
$$C = \frac{55.6325 \cdot 10^{-9}\,\varepsilon_r}{\ln\frac{D}{d}}$$

loop capacitance (F/km)

(14)
$$G = \omega C \tan\delta$$

dielectric conductance (S/km)

(15)
$$\alpha = 8.68589 \cdot \sqrt{\frac{1}{2}\left[\sqrt{(R^2 + \omega^2 L^2)(G^2 + \omega^2 C^2)} + (RG - \omega^2 LC)\right]}$$

characteristic attenuation (dB/km)

(16)
$$\beta = \sqrt{\frac{1}{2}\left[\sqrt{(R^2 + \omega^2 L^2)(G^2 + \omega^2 C^2)} + (\omega^2 LC - RG)\right]}$$

phase constant (rad/km)

(17) $$V_p = \frac{\omega}{\beta}$$

phase velocity (km/s)

(18) $$\tau = 10^6 \cdot \frac{\Delta \beta}{\Delta \omega}$$

group delay (μs/km)

(19) $$V_g = 10^6/\tau$$

group velocity (km/s)

(20) $$|Z| = \sqrt[4]{\frac{R^2 + \omega^2 L^2}{G^2 + \omega^2 C^2}}$$

modulus of characteristic impedance (Ω)

(21) $$\varphi = \tan^{-1} \frac{\omega L}{R}$$

(22) $$\psi = \tan^{-1} \frac{\omega C}{G}$$

(23) $$\vartheta = \frac{1}{2} (\varphi - \psi)$$

characteristic impedance angle

(24) $$\mathrm{Re}\, Z = |Z| \cdot \cos \vartheta$$

real part of characteristic impedance (Ω)

(25) $$\mathrm{Im}\, Z = |Z| \cdot \sin \vartheta$$

imaginary part of characteristic impedance (Ω)

(26) $$Z_{inf} = \sqrt{\frac{L_0}{C}}$$

modulus of characteristic impedance at infinite frequency (Ω)

The parameters μ_r, ε_r and $\tan \delta$ are generally functions of both the frequency f and the reference temperature.

I.2. - *Coaxial pair with inner and outer tubular conductors.*

The study of this coaxial structure mainly applies to large coaxial pairs and to carrier communication over power cables.

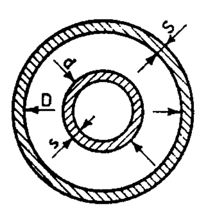

Fig. 3. - Cross section of coaxial pair with inner and outer tubular conductors.

Large coaxial pairs of this shape are generally employed for very high frequencies.

The transmission over power cables, usually covers the frequency band between 40 and 500 kHz.

The formulae previously described are modified only as far as the inner conductor is concerned.

Symbols are the same as in section I.1.

The depth of penetration of the inner conductor is given by:

$$(27) \qquad \delta_i = \frac{1}{\pi} \sqrt{\frac{\rho_i}{0.4 \cdot \mu_{ri} \cdot f}}$$

For sufficiently thin inner conductor ($\frac{s}{d} < 0.2$), the following approximate formulae can be used:

$$(28) \qquad k_i = \frac{s}{\delta_i} \frac{\mathrm{Sh}\,\frac{2s}{\delta_i} + \sin\frac{2s}{\delta_i}}{\mathrm{Ch}\,\frac{2s}{\delta_i} - \cos\frac{2s}{\delta_i}}$$

skin effect coefficient for inner conductor

The resistance of the inner stranded conductor is calculated as follows:

$$(33) \qquad R_{0i} = \rho_i \frac{4(1 + C_i)}{n \pi d_i^2}$$

d.c. resistance of inner conductor (Ω/km)

$$(34) \qquad R_i = R_{0i} \cdot k_i \cdot Q_i$$

effective resistance of inner conductor (Ω/km)
where:

k_i is expressed by (3) and Q_i is the spirality effect coefficient of inner conductor.

The resistance of the outer stranded conductor is calculated as follows:

$$(35) \qquad R_{0e} = \rho_e \frac{4(1 + C_e)}{N \pi d_e^2}$$

d.c. resistance of outer conductor (Ω/km)

$$(36) \qquad R_e = R_{0e} \cdot k_e \cdot Q_e$$

effective resistance of outer conductor (Ω/km)
where:

k_e is expressed by (6) and Q_e is the spirality effect coefficient of outer conductor.

The value of the « spirality effect coefficient » is given in fig. 6 (where d' is equal to d or D_0):

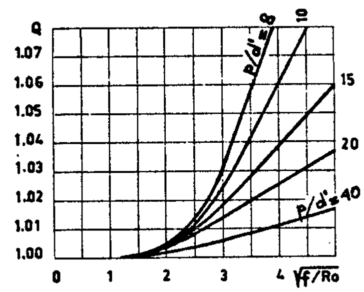

Fig. 6. - Spirality effect coefficient [3].

f = frequency (kHz)
p = pitch of spirals
d' = diameter of conductor
R_0 = conductor d.c. resistance (Ω/km)

For $f = 0$, the spirality effect coefficient is $Q(0) = 1$ and then Q increases with frequency.

However the increase of resistance due to spirality is usually a small fraction of the increase due to skin effect.

Calculation of L_i and L_e can be done with the following approximate formulae:

(37)
$$L_i = \left(\frac{4\rho_i}{\pi d^2}\right) \cdot \frac{q}{2\omega} \frac{(ber\, q)(ber' q) + (bei\, q)(bei' q)}{(ber' q)^2 + (bei' q)^2}$$

inductance of inner conductor (H/km)

(38)
$$L_e = 2 \cdot 10^{-4} \cdot \frac{\delta_e}{D_0 + \Delta} \cdot \frac{\mathrm{Sh}\,\frac{2S}{\delta_e} - \sin\frac{2S}{\delta_e}}{\mathrm{Ch}\,\frac{2S}{\delta_e} - \cos\frac{2S}{\delta_e}} \mu_{re}$$

inductance of outer conductor (H/km)

where:

$$\Delta \simeq 0.2\, d_e.$$

q and δ_e are given by (1) and (5) respectively.

Considering the particular shape of the inner conductor, L_0 and C are calculated by:

(39)
$$L_0 = 2 \cdot 10^{-4} \ln \frac{D_0 + \Delta}{\xi d}$$

inductance of space between conductors (H/km)

(40)
$$C = \frac{55.6325 \cdot 10^{-9} \varepsilon_r}{\ln \frac{D_0 + \Delta}{\xi d}}$$

loop capacitance (F/km)

where:

ξ is the « effective diameter factor » of the inner conductor, whose value is given in section I.4.

Cables of type b differ from type a in the shaping of inner conductor.

In such a case, R_i and L_i can be calculated by the following approximate expressions:

$$R_i = R_{0i} \cdot k_i \cdot Q_i \tag{41}$$

effective resistance of inner conductor (Ω/km)

$$L_i = 2.10^{-4} \frac{\delta_i}{d} \cdot \frac{\mathrm{Sh}\,\dfrac{2s}{\delta_i} - \sin\dfrac{2s}{\delta_i}}{\mathrm{Ch}\,\dfrac{2s}{\delta_i} - \cos\dfrac{2s}{\delta_i}} \cdot \mu_{ri} \tag{42}$$

effective inductance of inner conductor (H/km)
where:

R_{0i} is given by (33), k_i by (28) and δ_i by (27).

Due to stranding, an additional inductance L_p should be taken into account for both configurations a and b.

In fact, each single wire (having diameter d_i or d_e in fig. 5) describes a spiral of pitch p to which the following inductance in d.c. can be associated [8]:

$$L_p = \left[\frac{\pi \cdot \xi \cdot d^*}{p}\right]^2 \cdot 10^{-4} \cdot \mu_r \qquad \text{(H/km)}$$

being ξ the « effective diameter factor » (section I.4) and d^* the overall diameter of the layer considered.

The total inductance L_P due to stranding is given by

$$L_P = \sum_{1}^{n+N} L_p$$

Each L_p can be positive or negative according to the direction of spiralling.

For high frequencies, only layers run through by current have to be considered. However, in practice, the inductance L_P is usually a small, negligible part of the total inductance L.

I.4. - *Coaxial pairs with outer wire braid conductor.*

Only non magnetic conductors ($\mu_{ri} = \mu_{re} = 1$) are here considered. At frequencies higher than 10 MHz (where these cables are generally used), the following

approximate formulae can be employed for attenuation and impedance calculations:

$$(43)\quad \alpha = 87 \cdot \frac{\sqrt{F}}{Z_0}\left[\frac{k_1 \cdot k_{p1}}{d}\sqrt{\rho_i} + \frac{k_2 \cdot k_{p2}}{(D_0 + \Delta)}\sqrt{\rho_e}\right] + 91\sqrt{\varepsilon_r} \cdot F \cdot \tan\delta \qquad \text{(dB/km)}$$

$$(44)\qquad Z_0 = \frac{59.96}{\sqrt{\varepsilon_r}} \ln \frac{D_0 + \Delta}{\xi d} \qquad (\Omega)$$

The meaning of symbols employed is the following:

D_0 = diameter over solid dielectric (e.g. polyethylene (mm);
d = overall diameter of inner conductor (mm);
k_1 = stranding factor for attenuation;
k_2 = braiding factor;
k_{p1} = coating factor for inner conductor;
k_{p2} = coating factor for outer conductor;
ρ_i = resistivity of inner conductor (Ω mm²/km);
ρ_e = resistivity of outer conductor (Ω mm²/km);
ε_r = average relative dielectric constant of the insulation;
F = frequency in MHz;
$\tan\delta$ = tangent of loss angle of the dielectric;
Δ = additional thickness due to braid shaping of the outer conductor (mm);
ξ = effective diameter factor.

The parameters ξ and k_1 are functions of the number of wires n forming the inner conductor [6] as shown in the following table:

n	1	7	12	19
ξ	1	0.939	0.957	0.970
k_1	1	1.3	1.3	1.3

The braiding factor k_2 is given as a function of the diameter D_0 over the insulation, according to the following fig. 7.

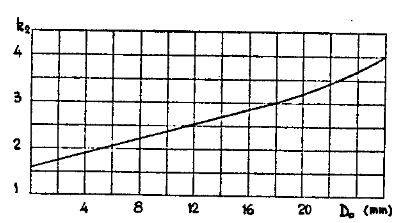

Fig. 7. - Braiding factor k_2 as a function of diameter over insulation D_0 [4].

When the construction details of the braided outer conductor are known, the braiding factor k_2 can be calculated by means of suitable formulae [5].

The coefficients k_{p1} and k_{p2} are the coating factors for inner and outer conductors respectively.

For uncoated conductors the coefficient is $k_p = 1$; for tinned or silver plated conductors, the coefficient k_p dependes on thickness and resistivity of tin or silver.

The following table shows the values of k_p for a tinned copper surface, where the tin thickness is equal to 0.005 mm.

Coating factor for tinned copper surface [6].

Frequency (MHz)	k_p
1	1
5	1
20	1.03
100	1.16
200	1.26
600	1.96
1 500	2.65
3 500	2.92

The additional thickness Δ takes into account the air layer between the solid insulation and the outer braided conductor. Usually Δ is small in comparison with D_0 and can be taken:

$$\Delta \simeq 0.7\, d_e$$

where:

d_e is the diameter of the braid wires.

To extend the calculations to frequencies lower than 10 MHz, it is necessary to calculate first of all the primary parameters R, L, C and G and than it is possible to obtain secondary parameters (α, β, Z, etc.) by means of formulae shown in section I.1.

The calculation of primary parameters for a braided conductor at frequencies lower than the ones previously examined is extremely complicated. However some approximate results can be obtained considering an outer conductor having the same d.c. resistance as the braided conductor i.e.:

$$S = \frac{\rho_e \cdot k_2}{R_{0e} \cdot \pi\,(D_0 + \Delta)} \tag{45}$$

equivalent thickness of outer conductor for skin effect evaluation (mm)

$$R_e = R_{0e} \cdot k_e \tag{46}$$

effective resistance of outer conductor (Ω/km)

$$(47) \quad L_e = 2 \cdot 10^{-4} \cdot \frac{\delta_e}{(D_0 + \Delta)} \cdot \frac{\mathrm{Sh}\,\dfrac{2S}{\delta_e} - \sin\dfrac{2S}{\delta_e}}{\mathrm{Ch}\,\dfrac{2S}{\delta_e} - \cos\dfrac{2S}{\delta_e}}$$

effective inductance of outer conductor (H/km)
where:

R_{0e} = is the d.c. resistance of the outer conductor;
k_e = is given by (6);
δ_e = is given by (5).

Moreover L_0 and C in such a case are given by:

$$(48) \qquad L_0 = 2 \cdot 10^{-4} \cdot \ln \frac{D_0 + \Delta}{\xi \cdot d}$$

inductance of space between conductors (H/km)

$$(49) \qquad C = \frac{55.6325 \cdot 10^{-9} \cdot \varepsilon_r}{\ln \dfrac{D_0 + \Delta}{\xi \cdot d}}$$

loop capacitance (F/km)

The value of ε_r shall take into account the presence of layer of air in the dielectric.

Considering for instance a cable with stranded inner conductor and braided outer conductor, it could be necessary to take into account two layers of air as shown in fig. 8.

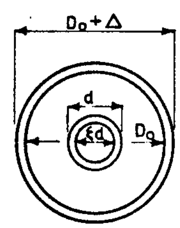

Fig. 8. - Insulation with two air layers.

In this case the average dielectric constant is given by:

$$(50) \quad \varepsilon_r = \frac{\ln \dfrac{D_0 + \Delta}{\xi d}}{\varepsilon_{r1} \cdot \ln \dfrac{D_0 + \Delta}{D_0} + \ln \dfrac{D_0}{d} + \varepsilon_{r1} \cdot \ln \dfrac{1}{\xi}} \cdot \varepsilon_{r1}$$

being ε_{r1} the dielectric constant of solid insulant (e.g. polyethylene).

However, if the interstices of the central conductor are well filled by insulation, only external air layer is to be considered so that (50) becomes:

$$(51)\qquad \varepsilon_r = \frac{\ln \dfrac{D_0 + \Delta}{\xi \cdot d}}{\varepsilon_{r1} \cdot \ln \dfrac{D_0 + \Delta}{D_0} + \ln \dfrac{D_0}{\xi \cdot d}} \cdot \varepsilon_{r1}$$

II. - DESIGN OF COAXIAL PAIRS.

The design of coaxial pairs by computer is described in detail only for structures with a solid inner conductor and a tubular outer conductor, which are the most used in the field of telecommunication cables.

The input data are generally the nominal values and tolerances of impedance and attenuation at a given frequency.

A certain range of variation for dielectric constant ε_r with the associated tan δ is also prefixed in order to give the possibility of choosing different types of insulation.

The various solutions are examined under the manufacturing, technical and economical points of view and one of them is chosen.

Considering the fact that the design data are usually given at high frequencies, the following approximate formulae can be employed for non magnetic conductors:

$$(52)\qquad \alpha = 87 \cdot \frac{\sqrt{F}}{Z_0} \cdot \left[\frac{\sqrt{\rho_i}}{d} + \frac{\sqrt{\delta_e}}{D}\right] + \\ + 91 \cdot \sqrt{\varepsilon_r} \cdot F \tan \delta$$

$$(53)\qquad Z = Z_0 + \frac{0.4772}{\sqrt{\varepsilon_r \cdot F}} \cdot \left[\frac{\sqrt{\rho_i}}{d} + \frac{\sqrt{\rho_e}}{D}\right]$$

$$(54)\qquad Z_0 = \frac{59.96}{\sqrt{\varepsilon_r}} \cdot \ln \frac{D}{d}$$

where:

- α = attenuation (dB/km);
- Z = characteristic impedance (Ω);
- Z_0 = impedance at infinite frequency (Ω);
- d = inner conductor diameter (mm);
- D = inner diameter of the outer conductor (mm);
- ρ_i = resistivity of inner conductor ($\Omega \cdot mm^2/km$);
- ρ_e = resistivity of outer conductor ($\Omega \cdot mm^2/km$);
- ε_r = average dielectric constant of the insulation;
- tan δ = tangent of loss angle of the dielectric;
- F = frequency in MHz.

From these expressions, considering for α and Z the design data, it is possible to calculate d and D:

$$d = \frac{1}{K} \cdot \left[\sqrt{\rho_i} + \sqrt{\rho_e} \cdot e^{-\frac{Z_0 \sqrt{\varepsilon_r}}{59.96}} \right] \tag{55}$$

$$D = d \cdot e^{\frac{Z_0 \sqrt{\varepsilon_r}}{59.96}} \tag{56}$$

where:

(57)

$$K = \frac{(\alpha - 91 \cdot \sqrt{\varepsilon_r} \cdot F \cdot \tan \delta) \cdot Z}{87 \cdot \sqrt{F} + \dfrac{0.4772}{\sqrt{\varepsilon_r \cdot F}} \cdot (\alpha - 91 \cdot \sqrt{\varepsilon_r} \cdot F \cdot \tan \delta)}$$

$$Z_0 = Z - \frac{0.4772}{\sqrt{\varepsilon_r \cdot F}} \cdot K \tag{58}$$

The thickness S of the outer conductor can be determined as a function of the diameter D. At first approach it can be taken $S \simeq 0.03\ D$.

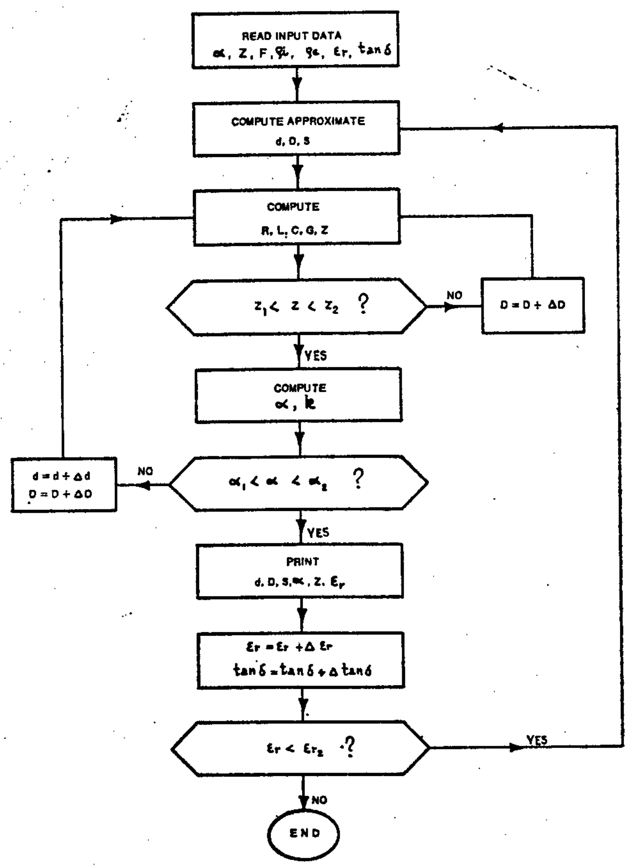

Fig. 9. - Flow-chart for design of coaxial pairs.

Primary parameters R, L, C, G and characteristic impedance Z can now be calculated with the precise formulae of section I.1.

If the calculated Z is not in the prefixed range $Z_1 < Z < Z_2$, a variation of D is considered.

This variation, taking into account (54), is given with the step:

$$\Delta D = \frac{\sqrt{\varepsilon_r}}{59.96} \cdot D \cdot \Delta Z \tag{59}$$

where ΔZ is the difference between the nominal and calculated values of Z.

Once the correct impedance Z has been obtained, the ratio $k = D/d$ is considered and the attenuation α is calculated with precise formulate of section I.1.

If the calculated attenuation is not in the prefixed range $\alpha_1 < \alpha < \alpha_2$, dimensions d and D are adjusted again.

From formula (52), the variation $\Delta \alpha$ as a function of Δd and ΔD is given by:

$$\Delta \alpha = -87 \cdot \frac{\sqrt{F}}{Z_0} \cdot \left[\frac{\sqrt{\rho_i}}{d^2} \cdot \Delta d + \frac{\sqrt{\rho_e}}{D^2} \cdot \Delta D \right] \tag{60}$$

With the scope to maintain the found value of Z, d and D are contemporary variated as follows:

$$\Delta D = k \cdot \Delta d \tag{61}$$

Substituting (61) in (60), Δd is given by:

$$\Delta d = - \frac{Z_0 \cdot \Delta \alpha}{87 \cdot \sqrt{F} \cdot \left[\frac{\sqrt{\rho_i}}{d^2} + \frac{\sqrt{\rho_e}}{D^2} k \right]} \tag{62}$$

being $\Delta \alpha$ the difference between the nominal and calculated values of attenuation.

With a few cycles, dimensions d and D are corrected in order to obtain attenuation and impedance in the prefixed limits. The computer prints d, D, S, α and Z for every value of ε_r (see fig. 9).

The outer conductor thickness S can be modified according to electrical, mechanical or economical criteria; then d and D could be recalculated giving S as an input value. This designing method is easily extensible, with some modifications, to other kinds of coaxial pairs.

III. - Tables and diagrams.

The calculations for the following coaxial pairs are shown:

a) C.C.I.T.T. standardized coaxial pairs
- 0.7/2.9 mm (foamed PE insulation)
- 1.2/4.4 mm (shaped PE insulation, bamboo type)
- 2.6/9.5 mm (PE disc insulation)

TABLE 1. - *Calculated characteristic parameters of 0.7/2.9 mm coaxial pair at 10 °C.*

F (MHz)	R (Ω/km)	L (mH/km)	α (dB/km)	β (rad/km)	$\lvert Z \rvert$ (Ω)	Re Z (Ω)	− Im Z (Ω)	V_p (km/s)	V_g (km/s)	τ (μs/km)	$\alpha/\sqrt{F}$
0.060	64.22	0.3396	3.455	1.7	83.00	80.77	19.11	224 480	236 970	4.220	14.105
0.100	68.32	0.3375	3.749	2.7	80.17	79.20	12.43	228 920	235 720	4.242	11.857
0.300	94.56	0.3244	5.348	8.0	77.15	76.92	5.90	235 700	242 260	4.128	9.765
0.500	115.00	0.3172	6.592	13.2	76.09	75.97	4.36	238 670	244 230	4.095	9.323
1.000	154.50	0.3093	8.995	26.0	75.00	74.94	2.96	241 940	246 190	4.062	8.995
4.287	312.60	0.2978	18.612	109.2	73.50	73.49	1.42	246 710	249 120	4.014	8.989
10.000	471.30	0.2939	28.350	253.0	73.01	73.00	0.92	248 350	249 940	4.001	8.965
12.888	533.60	0.2930	32.190	325.6	72.90	72.89	0.81	248 720	250 120	3.998	8.967
30.000	808.50	0.2908	49.270	754.9	72.62	72.61	0.53	249 680	250 600	3.990	8.996
52.224	1 063.30	0.2898	65.310	1 311.9	72.49	72.48	0.40	250 130	250 820	3.987	9.037
80.000	1 313.00	0.2892	81.230	2 007.4	72.41	72.41	0.32	250 390	250 970	3.985	9.082
100.000	1 467.00	0.2889	91.110	2 508.1	72.37	72.37	0.28	250 510	251 020	3.984	9.110

R_0 = 61.62 (Ω/km) C = 55.16 (nF/km) $G = 97 \cdot 10^{-6} \cdot F$ (S/km) $Z_{inf.}$ = 72.08 (Ω)

TABLE 2. - *Calculated characteristic parameters of 1.2/4.4 mm coaxial pair at 10 °C.*

F (MHz)	R (Ω/km)	L (mH/km)	α (dB/km)	β (rad/km)	$\lvert Z \rvert$ (Ω)	Re Z (Ω)	− Im Z (Ω)	V_p (km/s)	V_g (km/s)	τ (μs/km)	$\alpha/\sqrt{F}$
0.060	27.02	0.3066	1.472	1.5	80.27	79.75	9.19	256 600	264 440	3.782	6.009
0.100	32.23	0.2993	1.783	2.4	78.82	78.54	6.68	260 550	268 580	3.723	5.638
0.300	50.10	0.2851	2.850	7.0	76.55	76.46	3.55	267 620	273 030	3.663	5.204
0.500	63.80	0.2801	3.663	11.6	75.81	75.76	2.74	270 120	274 780	3.639	5.180
1.000	89.77	0.2745	5.206	23.0	75.00	74.97	1.95	272 940	276 550	3.616	5.206
4.287	182.00	0.2674	10.710	97.4	73.98	73.98	0.93	276 620	278 370	3.592	5.172
12.435	307.60	0.2647	18.210	281.0	73.59	73.59	0.55	278 060	279 100	3.583	5.164
30.000	475.80	0.2633	28.290	676.1	73.40	73.40	0.35	278 790	279 460	3.578	5.166
52.224	626.70	0.2627	37.370	1 176.0	73.31	73.31	0.26	279 110	279 630	3.576	5.171
61.160	677.90	0.2625	40.450	1 376.0	73.29	73.29	0.24	279 190	279 660	3.576	5.173
100.000	865.90	0.2621	51.810	2 249.0	73.24	73.24	0.19	279 400	279 760	3.575	5.181
300.000	1 497.00	0.2616	90.280	6 739.0	73.16	73.16	0.11	279 700	279 920	3.573	5.213
500.000	1 932.00	0.2614	117.000	11 228.0	73.13	73.13	0.08	279 800	279 960	3.572	5.235

R_0 = 21.20 (Ω/km) C = 48.87 (nF/km) $G = 14.7 \cdot 10^{-6} \cdot F$ (S/km) $Z_{inf.}$ = 73.05 (Ω)

Table 3. - *Calculated characteristic parameters of 2.6/9.5 mm coaxial pair at 10 °C.*

f (kHz)	R (Ω/km)	L (mH/km)	α (dB/km)	β (rad/km)	$\lvert Z \rvert$ (Ω)	Re Z (Ω)	— Im Z (Ω)	V_p (km/s)	V_g (km/s)	τ (μs/km)	$\alpha/\sqrt{F}$
0.050	5.14	0.3108	0.053	0.006	593.1	423.3	415.4	50 820	100 220	9.978	7.45
0.100	5.14	0.3108	0.074	0.009	419.5	302.2	290.9	71 190	137 770	7.259	7.38
0.500	5.14	0.3108	0.153	0.021	189.3	145.8	120.7	147 590	249 180	4.013	6.85
1	5.15	0.3107	0.198	0.033	137.3	113.0	78.0	190 420	280 860	3.560	6.26
5	5.39	0.3086	0.278	0.123	87.2	84.4	21.9	255 010	271 920	3.678	3.93
10	5.99	0.3039	0.318	0.239	82.8	81.8	12.5	262 920	272 350	3.672	3.18
20	7.29	0.2946	0.395	0.467	80.4	80.0	7.8	268 970	277 820	3.599	2.80
60	10.63	0.2807	0.594	1.363	77.9	77.8	3.9	276 530	281 980	3.546	2.423
100	13.07	0.2761	0.737	2.252	77.2	77.1	2.9	278 960	283 320	3.530	2.330
300	22.09	0.2687	1.263	6.660	76.1	76.0	1.7	282 880	285 930	3.497	2.305
500	28.52	0.2662	1.638	11.050	75.7	75.7	1.3	284 270	286 750	3.487	2.317

R_0 = 5.14 (Ω/km) C = 46.48 (nF/km) $G = 8.74 \cdot 10^{-9} f$ (S/km) $Z_{inf.}$ = 74.40 (Ω)

Table 4. - *Calculated characteristic parameters of 2.6/9.5 mm coaxial pair at 10 °C.*

F (MHz)	R (Ω/km)	L (mH/km)	α (dB/km)	β (rad/km)	$\lvert Z \rvert$ (Ω)	Re Z (Ω)	— Im Z (Ω)	V_p (km/s)	V_g (km/s)	τ (μs/km)	$\alpha/\sqrt{F}$
1.000	40.04	0.2636	2.312	22.0	75.31	75.31	0.91	285 700	287 430	3.479	2.312
2.500	62.88	0.2613	3.649	54.7	74.98	74.97	0.57	286 970	288 080	3.471	2.308
4.000	79.34	0.2604	4.615	87.4	74.86	74.85	0.45	287 430	288 310	3.468	2.307
10.000	125.00	0.2593	7.299	218.1	74.69	74.69	0.29	288 070	288 630	3.465	2.308
12.435	139.40	0.2591	8.142	271.1	74.66	74.66	0.26	288 180	288 680	3.464	2.309
20.000	176.50	0.2587	10.330	435.7	74.60	74.60	0.20	288 390	288 780	3.463	2.311
40.000	249.40	0.2583	14.640	870.8	74.55	74.55	0.14	288 620	288 910	3.461	2.315
61.160	308.20	0.2581	18.130	1 331.0	74.52	74.52	0.11	288 720	288 950	3.461	2.319
100.000	393.90	0.2579	23.250	2 175.0	74.49	74.49	0.09	288 820	288 990	3.460	2.325
200.000	556.80	0.2577	33.040	4 349.0	74.47	74.47	0.06	288 920	289 060	3.460	2.336
300.000	681.70	0.2577	40.610	6 523.0	74.45	74.45	0.05	288 970	289 070	3.459	2.345
400.000	787.10	0.2576	47.040	8 697.0	74.45	74.45	0.04	289 000	289 080	3.459	2.352
500.000	879.90	0.2576	52.740	10 870.0	74.44	74.44	0.04	289 020	289 090	3.459	2.359

R_0 = 5.14 (Ω/km) C = 46.48 (nF/km) $G = 8.74 \cdot 10^{-6} \cdot F$ (S/km) $Z_{inf.}$ = 74.4 (Ω)

b) power cable with inner and outer tubular conductors:

— inner conductor: outer nominal diameter 32.44 mm, thickness 4.72 mm (copper)
— insulation: oil impregnate paper, nominal diameter 57.2 mm
— outer conductor: nominal thickness 2.5 mm (lead)

TABLE 5. - *Calculated characteristic parameters of power cable 32.44/57.2 mm with tubular conductors at 20 °C.*

f (kHz)	R (Ω/km)	L (mH/km)	α (dB/km)	β (rad/km)	$\lvert Z \rvert$ (Ω)	Re Z (Ω)	— Im Z (Ω)	V_p (km/s)	V_g (km/s)	τ (μs/km)	$\alpha/\sqrt{F}$
10	0.77	0.123	0.208	0.409	18.99	18.97	0.77	153 610	155 530	6.430	2.08
20	1.01	0.122	0.301	0.812	18.83	18.82	0.44	154 770	156 640	6.384	2.13
40	1.49	0.120	0.501	1.611	18.67	18.67	0.26	156 040	158 150	6.323	2.51
60	1.86	0.118	0.698	2.404	18.58	18.58	0.15	156 800	158 720	6.300	2.85
80	2.16	0.118	0.897	3.196	18.52	18.52	0.08	157 260	158 950	6.291	3.17
100	2.42	0.117	1.106	3.987	18.49	18.49	0.02	157 580	159 070	6.286	3.50
150	2.96	0.117	1.695	5.963	18.42	18.42	— 0.11	158 060	159 280	6.278	4.38
200	3.42	0.116	2.391	7.936	18.39	18.39	— 0.21	158 340	159 400	6.274	5.35

R_0 = 0.492 (Ω/km) C = 343.31 (nF/km) $G = (35 f + 0.32 f^2) \cdot 10^{-6}$ (S/km)

c) Flexible coaxial pair 1/6.5 mm having solid copper inner conductor and outer wire braid copper conductor

— inner conductor: nominal diameter 1 mm
— insulation: solid PE, nominal diameter 6.5 mm
— outer conductor: braid, nominal wire diameter 0.1 mm

TABLE 6. - *Calculated characteristic parameters of flexible coaxial pair 1/6.5 mm at 10 °C.*

F (MHz)	R (Ω/km)	L (mH/km)	α (dB/km)	β (rad/km)	$\lvert Z \rvert$ (Ω)	Re Z (Ω)	$-$Im Z (Ω)	V_p (km/s)	V_g (km/s)	τ (μs/km)	$\alpha/\sqrt{F}$
0.060	31.2	0.425	1.7	2	80.09	79.72	7.67	185 700	189 460	5.28	6.96
0.100	38.8	0.418	2.1	3.3	79.06	78.85	5.79	187 750	192 310	5.20	6.78
0.300	64.2	0.400	3.6	9.8	77.07	77.00	3.26	192 250	195 680	5.11	6.65
0.500	81.2	0.394	4.6	16.2	76.44	76.40	2.49	193 780	196 470	5.09	6.57
1.000	112.6	0.388	6.5	32.2	75.81	75.79	1.74	195 330	197 260	5.07	6.51
4.000	220	0.380	12.9	127	75.05	75.05	0.85	197 250	198 220	5.04	6.48
12.000	377	0.377	22.6	381	74.74	74.74	0.48	198 070	198 630	5.03	6.52
30.000	594	0.376	36.2	950	74.58	74.58	0.30	198 480	198 840	5.03	6.61
61.160	846	0.375	52.6	1 934	74.50	74.50	0.20	198 700	198 950	5.03	6.73
100.000	1 080	0.375	68.5	3 160	74.46	74.46	0.16	198 800	199 000	5.03	6.85
200.000	1 525	0.374	100	6 317	74.42	74.42	0.11	198 920	199 060	5.02	7.07
500.000	2 409	0.374	168	15 785	74.38	74.38	0.06	199 020	199 110	5.02	7.51

R_0 = 23.97 (Ω/km) C = 67.55 (nF/km) $G = 170 \cdot 10^{-6} \cdot F$ (S/km) $Z_{inf.}$ = 74.31 (Ω)

Also the measured attenuation is given for these cables to allow comparison with calculated values. We point out that the slight difference between calculated and measured values is also due to the practical difficulty of determining accurately the dimensional values.

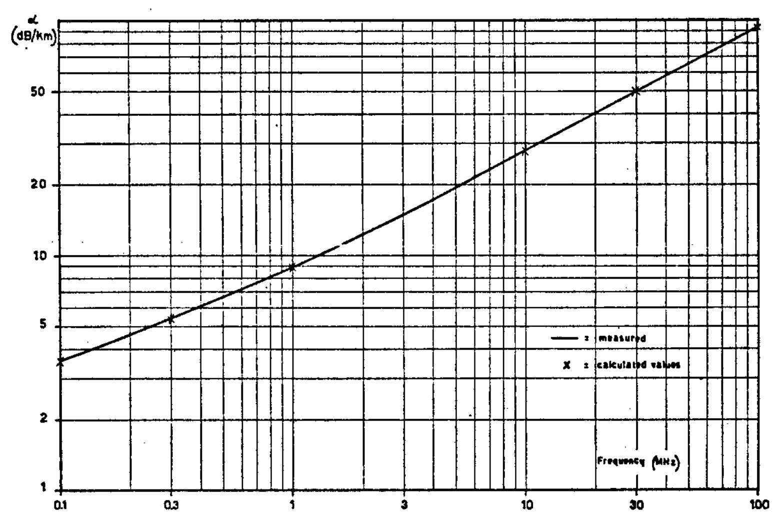

Fig. 10. - Attenuation of coaxial pair 0.7/2.9 mm at 10 °C.

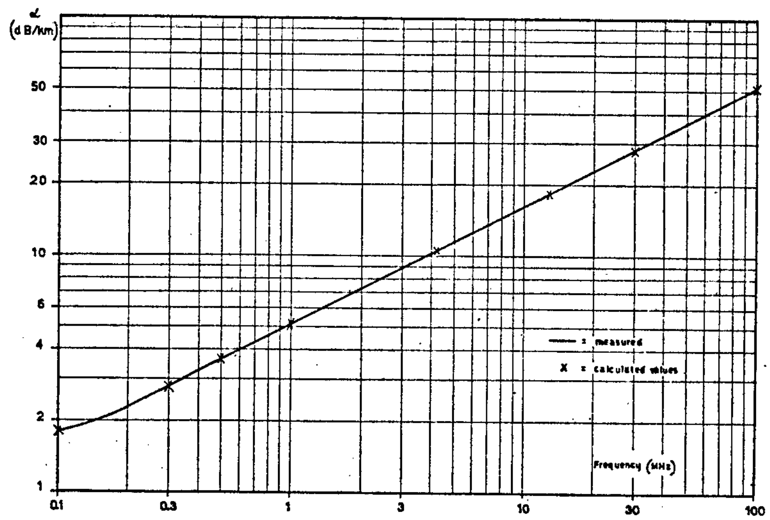

Fig. 11. - Attenuation of coaxial pair 1.2/4.4 mm at 10 °C.

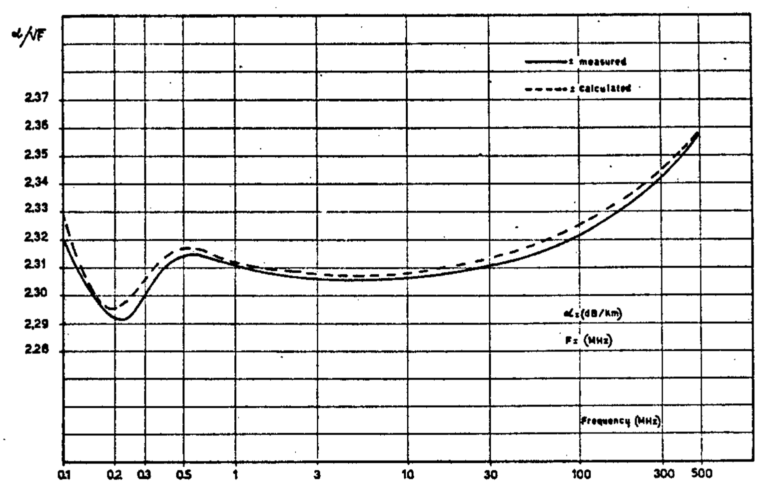

Fig. 12. - Ratio $\alpha/\sqrt{F}$ of coaxial pair 2.6/9.5 mm at 10 °C.

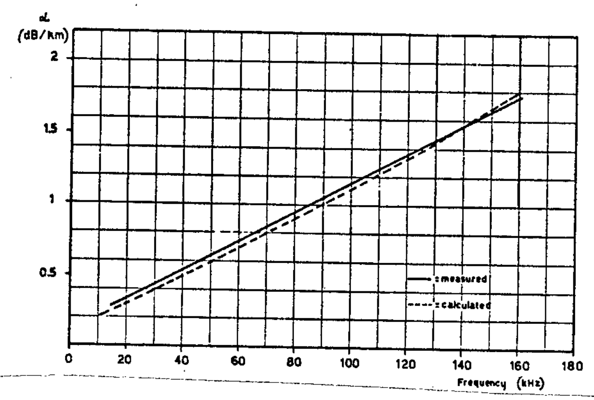

Fig. 13. - Attenuation of power cable 32.44/57.2 mm with tubular conductors at 20 °C.

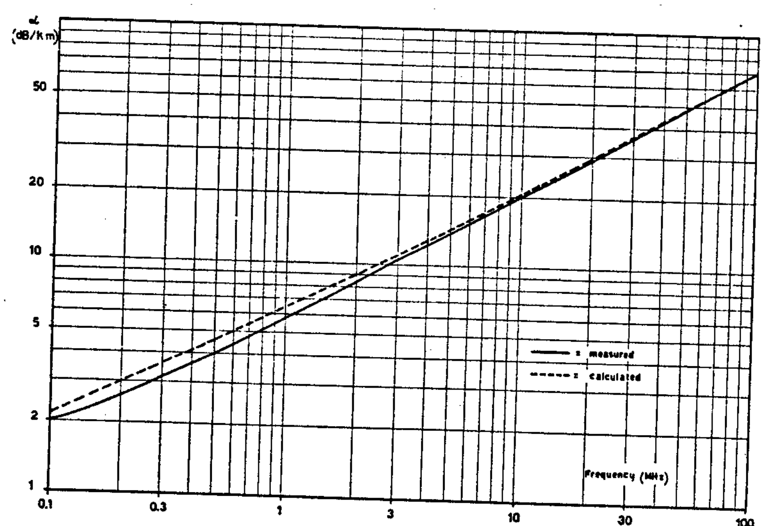

Fig. 14. - Attenuation of flexible coaxial pair 1/6.5 mm with outer wire braid conductor at 10 °C.

Conclusions.

The comparison between calculations and measurements confirm the utility of this paper.

The degree of accuracy is very high for coaxial pairs with solid inner conductor and outer tubular conductor that are the most employed in telecommunication field.

For the other ones, calculations are less precise but however in accordance with the approximation usually required.

The proposed design method allows to find coaxial pairs satisfying the input data with any prefixed tolerance.

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CSO: 5500

BRIEFS

KASTAMONU TV RECEPTION--Television broadcasts can be viewed from band 3 channel 6 in Kastamonu and its vicinity as of this evening. According to information obtained by the TRT [Turkish Radio and TV Administration] technical officials, viewers in Kastamonu and its vicinity should direct their antennas toward Ilgaz Mountain. [Text] [Ankara Domestic Service in Turkish 0530 GMT 4 Nov 77 TA]

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END